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KEENLEYSIDE POWERPLANT PROJECT
ENGINEERING DESCRIPTION

HYDROELECTRIC GENERATION PROJECTS DIVISION

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COLUMBIA RIVER
KEENLEYSIDE-MURPHY PROJECT
UPDATE

The Engineering Descriptions for the Keenleyside Powerplant Project (Report No. H 1560) and the Murphy Creek Project (Report No. H 1565) were prepared in November 1982 during the early stages of preliminary design. Since that time, on-going planning and design studies have resulted in some changes that would, to some extent, affect the project descriptions contained in these reports. The principal changes are as follows:

1. Construction Schedules

System Plan studies based on current load forecasts and alternative project sequences indicate earliest in-service dates of 1992 for Keenleyside and 1993 for Murphy Creek. The optional in-service date of 1990 mentioned in Report No. H 1560 for Keenleyside is no longer being considered.

2. Installed Capacities

Revisions to economic criteria may result in some reductions in the installed capacities selected for Keenleyside and Murphy. However, the changes are not expected to affect the arrangements or operation of the plants.

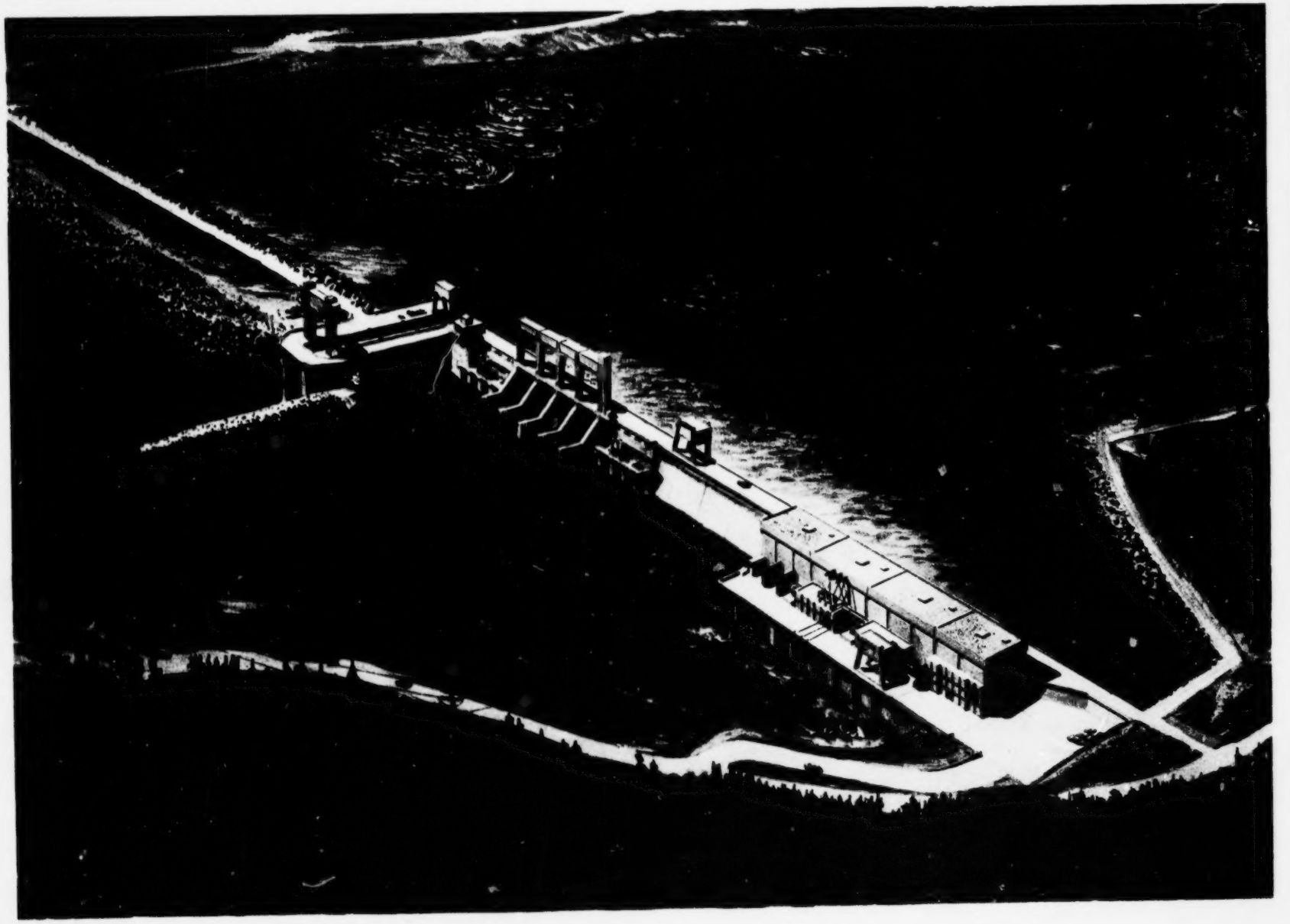
3. Keenleyside Turbine Setting

To improve flow characteristics in the powerplant and to maximize energy production in the pre-Murphy phase, the Keenleyside turbines

have been lowered by 3.0 m from El. 420 to El. 417. Due to improved cavitation characteristics this may also have a beneficial effect on fish passage.

4. Murphy Reservoir Shoreline Protection Works

Continuing geotechnical and property land use studies have resulted in small changes to the design and locations of shoreline protective works. Protective berms and fill is now considered as one of a number of possible mitigation options in low-lying and shallow sloping areas.



KEENLEYSIDE POWERPLANT PROJECT

COLUMBIA RIVER
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ENGINEERING DESCRIPTION

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SECTION 1.0 - INTRODUCTION

1.1 BACKGROUND

Under the terms of the Columbia River Treaty, the Hugh Keenleyside Dam was constructed to provide storage for downstream flood control and to increase power generation in the United States. The dam, an earthfill and concrete structure on the Columbia River 7 km upstream of Castlegar (see Figs. 1-1 and 1-2), was completed in late 1968. The dam controls runoff from a 36 500 km^2 drainage area and impounds a reservoir (Arrow Lakes Reservoir) of 8.8 x $10^9 m^3$ extending 233 km north to Revelstoke.

Provisions for generating facilities at Keenleyside Dam were investigated during the design of the dam (Ref. 1), but it was decided not to include them in the initial construction. Feasibility studies of the downstream Murphy Creek Project (Ref. 2) have been completed and because of the considerable interdependence of Keenleyside and Murphy, a prefeasibility level study for Keenleyside (Ref. 3), was undertaken to permit a combined optimization of both projects. Keenleyside was studied in combination with several alternative reservoir levels for the Murphy Creek Project. In addition to a "no Murphy" case, alternative Murphy reservoir levels of El. 424, El. 427 and El. 430 were investigated. These levels are respectively 4, 7 and 10 m above the existing tailwater level at Keenleyside under average flow conditions and, therefore, would significantly affect the potential generating capability at Keenleyside. Similarly, the Murphy Project would affect generation at Cominco's Brilliant plant. Based on subsequent optimization studies (Ref. 4), a Murphy reservoir level of El. 424 was selected as the basis for further studies (Ref. 5).

1.2 ONGOING STUDIES

In July 1981, when the Prefeasibility Study for Keenleyside was completed, studies for the Murphy Creek Project were already well into the Preliminary Design phase. Because of the interdependence of the two projects it was decided to omit the feasibility level study for Keenleyside and commence Preliminary Design studies in September 1981. Phase 1 of these studies has included field investigations and office studies sufficient to permit all major decisions to be reached on the following project features:

1. arrangement of structures,

2. type and number of units,

3. optimum turbine and generator capacity.

During the subsequent Phase 2, all of the major project components will be optimized.

SECTION 2.0 - GEOGRAPHIC SETTING

2.1 COLUMBIA RIVER DEVELOPMENT

The Columbia River flows a distance of 760 km from its source in Columbia Lake to the Canada - U.S.A. border near Trail; in this course, it falls about 410 m from El. 810 to El. 400 (see Fig. 2-1).

Mica Dam became operational in 1973 and provides $14.8 \times 10^9 m^3$ of live storage, of which $8.6 \times 10^9 m^3$ are committed to operation under the Columbia River Treaty. Power facilities at Mica develop a head of about 170 m and have an ultimate rated capacity of 2610 MW. The regulated discharge from Mica has made possible a run-of-the-river plant at Revelstoke with a comparable power output. Construction of the 2700 MW Revelstoke Project began in 1976. The Arrow Lakes Reservoir, formed by the Hugh Keenleyside Dam, became operational in 1968.

2.2 AREA DESCRIPTION AND PROJECT LOCATION

From the Mica Project to the lower portion of the Arrow Lakes Reservoir, the Columbia River flows from north to south in a well defined, generally steep-sided, narrow valley. The valley sides are heavily forested. Adjacent to the valley the higher peaks rise to about El. 3050. Near the lower end of the reservoir the Columbia River changes its course eastward for about 16 km to Castlegar where it again turns southward and is joined by the Kootenay River. The Hugh Keenleyside damsite is located within the east-west reach, some 7 km upstream of Castlegar (see Fig. 1-2).

From Castlegar the damsite can be reached by paved highways on either side of the Columbia River. The Canadian Pacific Railway also passes the damsite on the south side of the river.

SECTION 3.0 - GENERAL DESCRIPTION

3.1 EXISTING FACILITIES

The Hugh Keenleyside damsite is situated at a point where granodiorite bedrock occurs at a fairly shallow depth on the left (north) abutment but dips steeply southward under the original riverbed. The dam, therefore, comprises a 360 m length of concrete structures founded on bedrock on the left abutment and a 450 m long earthfill dam founded on silts, sands and gravels in the riverbed and on the right abutment. To control seepage under the earthfill dam, an impervious till blanket was constructed extending some 600 m upstream of the dam. The general arrangement of the existing facilities is shown on Fig. 3-1. An upstream elevation of the dam and typical sections through the principal structures are shown on Figs. 3-2 and 3-3.

The concrete structures comprise, from the left abutment, the 100 m long north bulkhead; low level ports Nos. 1 to 4 (four 6.1 m wide x 7.3 m high gated outlets at sill El. 411.5); the sluiceway containing four 15.2 m wide x 16.8 m high vertical lift gates at a crest level of El. 424.9; low level ports Nos. 5 to 8 (similar to Nos. 1 to 4); the navigation lock (15.2 m wide and 88 m between gates); and the south bulkhead section connecting with the earthfill dam.

The earthfill dam is comprised mainly of sand and gravel fill with an upstream impervious till core connecting with the blanket. The maximum height of the dam, above the original riverbed, is approximately 52 m.

The crest level of the concrete structures is El. 443.8 rising to El. 444.7 at the left abutment and at the earthfill dam.

The normal maximum reservoir level is El. 440.1. However, the dam was designed for temporary surcharge to El. 441.7. To improve flow regulation for downstream U.S. powerplants, and with the permission of the Comptroller of Water Rights, the reservoir has been temporarily surcharged to El. 440.7 in seven of the last 12 years. Between El. 440.1 and the normal minimum reservoir level of El. 419.6, the reservoir contains a useable storage of $8.8 \times 10^9 m^3$. The 0.6 m surcharge contains an additional $0.3 \times 10^9 m^3$.

3.2 PROPOSED GENERATING FACILITIES

The proposed generating facilities would be located on the left (north) bank, between the existing discharge facilities and the Robson-Broadwater Highway, as bedrock suitable for the powerplant foundation is present only on the north abutment.

During the prefeasibility studies three basic arrangements were considered. One would involve a 900 m long canal skirting the impervious blanket as suggested during earlier studies in 1962. The second arrangement would utilize four of the eight low level ports as intakes for two generating units. The third and proposed alternative would comprise a powerhouse adjacent to the end of the existing north bulkhead section with a short intake approach channel connected to the reservoir immediately upstream of the dam.

SECTION 4.0 - RESERVOIR OPERATION AND FLOWS

4.1 EXISTING OPERATING REGIME

In most years under the existing operating regime for the Arrow Lakes Reservoir, use is made of close to the maximum available live storage. This results in a fairly long period, generally mid-January to mid-June, when the Arrow Lakes Reservoir level is below practical generation levels.

To assess potential powerplant operation under the existing regime, a computer simulation of the Arrow Lakes Reservoir operation was conducted, based on the 1985/86 Assured Operating Plan under the Columbia River Treaty. Regulated reservoir levels and releases for both the Columbia and Kootenay rivers were based on the 35-year period of historical stream flows from August 1940 to July 1975. A monthly time interval was used in the simulation.

A summary of monthly mean reservoir levels and discharges for Keenleyside based on the existing reservoir operation (Regime 1) is shown on Fig. 4-1. In order to indicate the head available at Keenleyside, the monthly mean tailwater levels (assuming a nominal Murphy reservoir level of El. 424) are also shown. Thirty-five year maximum, mean, and minimum values of reservoir level, tailwater level and total discharge are given for each month. As illustrated on the plot of tailwater levels for Regime 1, the Murphy reservoir level would have to be drawn down below El. 424 generally from mid-January to mid-June to permit the regulated releases from Keenleyside. (If the Murphy reservoir level is too high and the Arrow Lakes Reservoir too low, the Keenleyside discharge capacity is insufficient.)

Mean (35-year) monthly gross heads at Keenleyside for the Murphy 424 case shown would range from 0.6 m in March to 15.9 m (16.5 m with the 0.6 m surcharge) in August. Although not included in the computer simulations, it has been assumed that the temporary reservoir surcharge in high runoff years would continue in the future on the same basis as in recent years. The mean gross head from February to May, inclusive, would be only 1.3 m if future Keenleyside operation were to be based on the 1985/86 Assured Operating Plan.

Mean (35-year) monthly total releases from Keenleyside would range from about 600 m^3/s to 2400 m^3/s with the highest releases generally in January and February during reservoir drawdown. The 35-year mean discharge from Keenleyside based on this study is 1150 m^3/s.

4.2 FUTURE OPERATING REGIME

Because of the major drawdown of the Arrow Lakes Reservoir if operated under the existing regime, the Keenleyside Powerplant would have to be shut down for about 5 months/year. (The head at Murphy would also be significantly reduced during this period to permit the Keenleyside releases.)

To maximize generation at Keenleyside and Murphy and to mitigate potential environmental impacts caused by reservoir drawdown, several alternative operating regimes for the Columbia River system have been investigated. One of these, termed Regime 2, involves a reduction of about $2.5 \times 10^9 m^3$ in the mean annual drawdown volume of the Arrow Lakes and an increase of about 6.6 m in the mean annual minimum reservoir level. A summary of monthly mean reservoir levels, tailwater levels and discharges for the future Regime 2 is shown on Fig. 4-2.

Under mean water conditions with Regime 2, downtime at Keenleyside due to insufficient head (Arrow Lakes Reservoir levels less than El. 430)

would be reduced from about 5 to 2 1/2 months/year and the Murphy Reservoir, in most years, would not have to be drawn down to permit the Keenleyside releases. Additional information regarding power production under Regime 2 is presented in Section 7.0.

For most of the project life Regime 2 is expected to be much more representative of operation than Regime 1. For this reason Regime 2 has been chosen as the basis for project design. When the operating flexibility of the Columbia River Treaty projects improves following expiration of the Treaty, it is expected that the operating regime may be further refined to increase power generation, improve flood control at Trail or reduce the environmental impacts of reservoir drawdown.

4.3 FLOOD FLOWS

To assess the impact of the Murphy Reservoir on the flood discharge capability of the existing facilities at Keenleyside and to establish cofferdam levels during construction, a review was made of flood criteria and magnitudes. Estimates were made (Ref. 7) of the Probable Maximum Flood and the Diversion Design Flood.

The Probable Maximum Flood for Keenleyside Dam was estimated using computer modelling of the basin. Runoff conditions resulting in the Probable Maximum Flood peak flow would be produced by the joint occurrence of an extremely high snowpack in early July and a 20-day extreme temperature sequence (return period of 1000 years). This weather sequence would be followed by the Probable Maximum Rain event at a time when the Arrow Lakes and upstream reservoir flood control capability would not be available to attenuate the peak runoff from the Probable Maximum Rain event.

The Diversion Design Flood was estimated as the peak 24-hour discharge from the Arrow Lakes Reservoir that would occur on average once in

30 years. This flow was used to size the downstream cofferdam required for constructing the powerhouse. The flood peak risk at the damsite is determined largely by the residual runoff potential, the residual flood regulation capability, and by the meteorological events occurring in the final stages of the Treaty reservoir refill operation (scheduled to finish on 31 July). The study assumed that only minimum discharges would be passed at each of the projects until reservoir refill was achieved. After the time of refill, all reservoir inflows would be passed.

The results of the study are as follows:

Event	Columbia River Discharge at Keenleyside Dam	Kootenay River Discharge*1 at Brilliant (concurrent)
Probable Maximum Flood	10 300 m^3/s	2800 m^3/s
Diversion Design Flood	4 290 m^3/s	2020 m^3/s

Note: *1 Discharge from the Kootenay River also affects the Keenleyside tailwater levels and, therefore, the required height of the downstream cofferdam.

Finally, it was determined that the construction of a project at Murphy Creek with a reservoir level of 424 m would not reduce the discharge capacity at Keenleyside below that required for the passage of floods of magnitude up to and including the Probable Maximum Flood.

SECTION 5.0 - FEATURES OF GENERATING FACILITIES

5.1 APPROACH CHANNEL

The approach channel leading from the reservoir to the powerplant (see Fig. 5-1) would have an average length of about 150 m and a maximum top width of about 230 m near the channel entrance. The invert level at the entrance has been kept at a fairly high level, El. 423, to minimize the amount of earthwork following cofferdam removal. Such a level is practical because, due to turbine head limitations, the powerplant would not operate at reservoir levels lower than El. 430. From the entrance at El. 423 to the debris trap at El. 407.5 in front of the powerplant intake, the channel invert would slope downward at a slope ranging from about 4H:1V to 10H:1V. The channel would be excavated primarily in sands and gravels, except for the area immediately in front of the powerhouse where bedrock would be encountered.

Because the approach channel would cut through the impervious blanket which currently prevents seepage through the left abutment past the concrete structures and through the sands and gravels underlying the earthfill dam, a new blanket would have to be connected in the vicinity of the cofferdam and extended along the invert and left bank of the channel to the point where it could be tied to bedrock. Seepage past the concrete structures via the left abutment would no longer be possible as these structures would be founded directly on bedrock to above maximum reservoir levels.

All of the critical work on the extension of the impervious blanket would be carried out in the dry behind the cofferdam (see Fig. 5-2) under controllable conditions. The existing blanket throughout this area was originally placed in the dry and, therefore, the details of its construction are well known.

Riprap with sand and gravel bedding would be placed over the entire surface of the blanketed channel for protection against wave and scour action and against freezing or drying out of the blanket during periods when the reservoir is low.

5.2 POWERPLANT

(a) Powerplant Capacity

The total installed capacity of 210 MW was selected following an economic study in which the turbine and generator capacities were optimized to produce the highest net annual benefits. On the basis of this optimization study and considering the limits of current experience with large size Kaplan turbines at heads similar to that at Keenleyside, three vertical shaft Kaplan turbines were selected.

(b) Powerhouse

The powerhouse (see Figs. 5-1 and 5-3) would contain three 70 MW vertical shaft Kaplan turbines and generators, with a service bay at the north end. The powerhouse would be located between the end of the existing north bulkhead and the Robson-Broadwater Highway. Excavation for the powerplant would expose an extensive area of bedrock rising to the north to above dam crest level, and a bulkhead section would be extended from the powerplant to this area.

The indoor powerhouse would have a machine hall 23.5 m wide x 90 m long, plus a 24.5 m long service bay. A single 500-t overhead bridge crane would be provided.

(c) Intakes

The intakes would be integral with the powerhouse and, for each unit, would comprise three openings separated by piers with trashracks at the upstream face, guides for service bulkheads or stoplogs a short distance downstream, and hydraulically controlled operating gates. Servicing of this equipment would be accomplished by means of an existing, modified 82 t gantry crane. An 8.5 t capacity jib crane, attached to the gantry crane, would be used in conjunction with a hydraulic grapple for removal of debris from the trap in front of the intakes.

(d) Turbines

The three turbines would be vertical shaft Kaplan units operating at 66.67 rpm and developing their rated output of 71 100 kW at a net head of 16.0 m. The rated discharge of each unit would be approximately 500 m^3/s. The combined three-unit discharge of 1500 m^3/s is about 30 percent higher than the long-term average flow (1150 m^3/s) of the Columbia River at the Keenleyside damsite. Considering the head range limitations of the turbines, it has been assumed that the plant would be shut down when the gross head is less than 7.0 m, corresponding to a reservoir level of about El. 430. The turbine and generator ratings would permit full gate output with the Arrow Lakes Reservoir surcharged from El. 440.1 to 440.7 in years of high runoff.

(e) Generators, Transformers and Switchgear

The three generators would be of the umbrella or semi-umbrella type, having a synchronous speed of 66.67 rpm and a rated capacity of 70 MW (0.90 power factor). Each generator would be connected by naturally cooled isolated phase bus to a three phase generator

transformer which would be rated 80 MV.A (13.8 kV-230 kV). No spare transformer would be provided.

Generator circuit breakers would be located in the downstream gallery between the generators and generator transformers.

The generator transformers and 230 kV switchgear would be located on the downstream tailrace deck. The 230 kV switchgear would consist of circuit breakers, disconnect switches, ground switches and bushings all metalclad and insulated with compressed gas (SF6). This switchgear would connect to 230 kV overhead transmission lines attached to the downstream side of the powerhouse roof.

Station service would be provided from taps off the low voltage buses at 13.8 kV from each unit.

(f) System Control

The Keenleyside Powerplant would be remotely controlled through the B.C. Hydro microwave system from the Cranbrook Control Centre and from the Burnaby Mountain System Control Centre near Vancouver.

5.3 TAILRACE AND TAILRACE WEIR

The tailrace channel would have a length of about 150 m and an invert width of 60 to 70 m at El. 414. The excavation for this channel would involve mainly overburden with some rock excavation near the powerhouse. Although maximum velocities in the channel would be in the order of only 2 m/s, it is expected that some turbulence would occur during operation of the sluiceway and low level ports; therefore, riprap slope protection would be provided.

Based on the preliminary 1983/84 System Plan, the Keenleyside powerplant would be in service in August 1992 but the Murphy Creek project would not come into service until July 1993. To maintain adequate turbine submergence (necessary to avoid turbine cavitation damage) during this 1 year period, the downstream cofferdam would be left in place with an 80 m portion of its length lowered from El. 426 to about El. 420 to act as a weir. This would allow the tailwater level upstream of the cofferdam to be maintained at levels near the future Murphy reservoir level.

5.4 TRANSMISSION

As separate engineering and environmental reports are being prepared for the transmission line, no detailed engineering description of the transmission facilities to the Murphy Creek Project and Selkirk Substation is included in this report.

5.5 ACCESS

At the present time public access is provided on the dam crest, connecting the paved highway on the south side of the river with the Robson-Broadwater Highway on the north side of the river. Because of the very tight bends at the navigation lock, traffic is limited to small vehicles, the largest generally being a school bus. Due to the limited visibility in this area, traffic is permitted only in one direction at a time and is controlled by traffic lights maintained by the B.C. Ministry of Transportation and Highways.

During construction of the generating facilities, access across the dam would be maintained by rerouting the roadway over the upstream cofferdam. However, because of the narrow crest width and a sharp 90° bend where the cofferdam would abut the north bulkhead, the one-way traffic limitation at the lock would be extended to the west end of the

cofferdam. Upon completion of the generating facilities, the roadway would be permanently located across the powerplant intakes.

Because of the extensive excavation required for the approach channel, powerplant and tailrace channel, some 1200 m of the existing Robson-Broadwater Highway would have to be realigned. Advantage would be taken of this realignment to shorten the access routes across the dam and to the powerplant service bay.

SECTION 6.0 - CONSTRUCTION

6.1 CONSTRUCTION SCHEDULE

In accordance with the preliminary 1983/84 B.C. Hydro System Plan, the current engineering schedule for the Keenleyside Powerplant requires completion of Phase 1 of Preliminary Design by 30 April 1983 and completion of Phase 2 of Preliminary Design by 30 April 1984. It is proposed to apply for an Energy Project Certificate (EPC) in mid-1983. It has been assumed that B.C. Hydro would be awarded an Energy Project Certificate for Keenleyside by 1 January 1985.

The proposed construction schedule for the 210 MW Keenleyside Powerplant is shown on Fig. 6-1 and is based on in-service dates specified by the preliminary 1983/84 System Plan.

To achieve the August 1992 in-service date for the first unit it would be necessary to begin construction in late 1986. This mid-winter starting date for the first contract (for cofferdams, excavation and construction facilities, primarily) is necessary to take advantage of the annual low reservoir period for construction of the upstream cofferdam. With award of the first contract by 1 September 1986 and some 4 1/2 months for tendering and bid evaluation, the tender documents for this critical contract would have to be issued in mid-April 1986.

Because of the extensive model testing required for the large diameter, low head Kaplan units, the desirability of having finalized powerhouse water passage dimensions prior to tendering the main civil contract, and in order to confirm the turbine type and approximate powerhouse dimensions prior to the close of tenders for cofferdams and excavation, it would be necessary to issue tender documents for the turbines and generators in March 1986 and award these contracts by September 1986.

With final powerhouse dimensions available in late 1987 it would be possible to issue tender documents for the main civil contract by 1 March 1988 and award the contract by August 1988. Placement of powerhouse concrete would start approximately 7 months later.

The overall construction period, from award of the first contract in September 1986 to the August 1992 in-service date for Unit 1, would be 6 years. Units 2 and 3 are scheduled to be in-service in December 1992 and August 1993, respectively. The in-service dates of all three units are governed to some extent by the annual low reservoir period from January to June (Regime 1).

6.2 SEQUENCE OF CONSTRUCTION

Construction would begin in November 1986 with the construction camp and offices. In January 1987 work would proceed on the upstream cofferdam. While the Arrow Lakes Reservoir is drawn down early in the year some of the existing sand and gravel fill overlying the till blanket would be removed allowing connection of the impervious core of the cofferdam with the existing till blanket. Because of the annual reservoir drawdown only a small amount of rockfill for the toe of the cofferdam would have to be placed under water. The remainder of the earth and rockfill would be placed in the dry as the reservoir begins to refill.

The downstream earth and rockfill cofferdam would involve considerable excavation and backfill. This work would start in February 1987 and would be complete by March 1988.

While the cofferdams are being constructed, work would proceed on the main excavation but would be restricted to material above El. 442 until the upstream cofferdam is tested for seepage under full head. This testing prior to breaching the left abutment is considered necessary because the upstream cofferdam will function essentially as the main dam

for 5 years. Other early work would include relocation of the Robson-Broadwater Highway.

While the cofferdam and excavation work is under way in 1987 and early 1988, the main civil contract for the powerplant would be tendered, with award of the contract in August 1988. Following mobilization, the batch plant and construction cranes would be installed so that placing of concrete could begin in April 1989.

Assembly and installation of the turbine for Unit 1 would begin in October 1990 with Units 2 and 3 following at about 4 to 6-month intervals. Allowing 22 months for turbine and generator installation and testing of each unit, the first unit would be in-service by 1 August 1992 with Units 2 and 3 following in December 1992 and August 1993, respectively.

The upstream cofferdam would be removed during the low reservoir period in early 1992. At about the same time, the downstream cofferdam would be modified for use as a tailrace weir and would remain in place until the Murphy Project is in service in mid-1993.

It should be noted that all of the scheduled dates mentioned in this section and the preceding Section 6.1 are based on a Unit 1 in-service date of August 1992 as stipulated by the preliminary 1983/84 B.C. Hydro System Plan. In consideration of public pressure to accelerate the project and in the event of changes in the estimated load growth, B.C. Hydro is maintaining a study schedule that would permit an optional Unit 1 in-service date of September 1990 - nearly 2 years earlier. However, some of the early work could not be advanced by the same 2 years and the overall construction schedule would have to be compressed from 6 to 5 years. The principal differences between the two schedules would be as follows:

	1992 In-service Schedule	1990 In-service Schedule
Unit 1 In-service	Aug. 1992	Sep. 1990
Unit 2 In-service	Dec. 1992	Aug. 1991
Unit 3 In-service	Aug. 1993	Oct. 1991
Assumed project approval	Jan. 1985	Feb. 1984
Award turbine and generator contracts	Sep. 1986	Aug. 1985
Award cofferdam and excavation contract	Sep. 1986	Aug. 1985
Award main civil contract	Aug. 1988	Dec. 1986
Construct cofferdams	1987	1986
Start powerhouse concrete	Apr. 1989	Jul. 1987

6.3 CONSTRUCTION METHODS AND PLANT

The methods and equipment employed for construction of the generating facilities would be of the Contractors' choice. However, for planning purposes, certain assumptions have been made as to the construction methods.

For the cofferdam and excavation contractor, the main activity would involve the placement of some 300 000 m^3 of rock and earthfill in the upstream and downstream cofferdams plus the excavation and disposal of some 1.6 x $10^6 m^3$ (in situ) of silts, sands, gravels and rock. The only suitable spoil areas for the excavated materials appear to be on the north bank of the reservoir approximately 1 to 3 km upstream of the dam (Areas 4, 5, 6, 7, 10, 11 and 12 on Fig. 6-2).

For the main powerplant contractor, the principal activity would be the batching and placing of some 160 000 m^3 of concrete. The total amount of processed concrete aggregate required would be approximately 190 000 m^3 (340 000 t). Although some of the material may come from required excavation, it is expected that most of the aggregate would be

obtained from one of the borrow areas used for the dam construction in the 1960s. This borrow area is located along the Robson-Broadwater Highway, 1.8 km upstream of the dam (see Area 6 on Fig. 6-2).

Up to about 60 000 m^3 of glacial till may be required for extension of the impervious blanket through the approach channel for the powerplant. It is expected that this material, along with about 80 000 m^3 of till for the cofferdams, would be obtained from the original Balfour borrow pits (Area 9 on Fig. 6-2) northeast of the damsite. B.C. Hydro still holds a reserve on the Crown property in this area.

6.4 CONSTRUCTION CAMP

The offices and single labour camp would be located on the north bank, approximately 0.7 km downstream of the dam (see Figs. 6-2 and 6-3). This location would provide good access to all work areas and is on property owned by B.C. Hydro. The camp would accommodate approximately 60 percent of the peak labour force of about 540 with the remainder assumed to reside off-site. As shown on Fig. 6-3 the proposed camp would include four two-storey, 80-man bunkhouses, a 350-man dining hall and a recreation hall. Parking would be provided for approximately 200 cars in the immediate vicinity of the camp.

Other facilities would include offices for B.C. Hydro and Columbia Hydro Constructors and a materials testing laboratory at the west end of the campsite. Parking would be provided here for approximately 50 cars.

Domestic water would be supplied from two wells drilled in the camp area. For emergency use, two water reservoirs would be located on the higher levels north of the camp and near the highway.

A sewage treatment plant would be constructed at the east (downstream) end of the campsite. Effluent treatment would conform to the requirements of the B.C. Pollution Control Board.

Electric power would be obtained from West Kootenay Power and Light which has a distribution line and 69 kV substation in the immediate area.

6.5 COFFERDAMS

Temporary cofferdams both upstream and downstream of the existing dam would be required for construction of the powerplant.

As shown on Fig. 5-2, the upstream cofferdam would be located at the entrance to the powerplant approach channel. It would be a rock and earthfill structure having a length of about 180 m, a height of about 20 m and a fill volume of approximately 90 000 m^3. As shown on Fig. 5-3, it would have an impervious till core connected to the existing till blanket which extends some 600 m upstream from the dam. To comply with the requirements of the Columbia River Treaty and because of the high value of the 0.6 m reservoir surcharge, the crest level of the upstream cofferdam has been set at El. 442 - high enough to permit maximum reservoir operating levels.

The downstream cofferdam is located across the powerplant tailrace channel and would be tied into the existing north bulkhead. It would be a rock and earthfill structure having a length of about 170 m and a maximum height above bedrock of about 30 m. As shown on Fig. 5-3, an impervious cutoff down to bedrock would be provided by first excavating through the existing overburden and fill and then backfilling with a till core. The upper levels of the core would be protected by rockfill shells. Construction of the downstream cofferdam would require some 150 000 m^3 of excavation and 200 000 m^3 of fill. The crest level of

El. 426 is based on the Diversion Design Flood having a return frequency of 1 in 30 years (see Subsection 4.3). It has been assumed also that the cofferdams at the downstream Murphy Creek Project would be installed while the Keenleyside Powerplant is still under construction. The Murphy Creek cofferdams would result in a slight increase in water levels at the Keenleyside Dam under Diversion Design Flood conditions.

6.6 SPOIL AREAS

Seven potential spoil areas are shown on Fig. 6-2. They comprise two sites (Areas 11 and 12) above the Robson-Broadwater Highway and five sites (Areas 4, 5, 6, 7 and 10) on the north shore of the Arrow Lakes Reservoir.

Areas 11 and 12 above the Highway are old borrow areas that would be refilled to approximately the original topography. Area 10 is also an old borrow area but lies between the north bank of the reservoir and a long, slender island some 80 m offshore (at full reservoir). The remaining four areas would be developed by first constructing retention dykes during the annual low reservoir period. These dykes would be constructed in the dry at a foundation level of about El. 430 or higher and would be extended upward, as the reservoir refills, to above maximum reservoir level. Granular and rockfill protection would be placed on the face of these dykes to prevent erosion.

The spoil material would be deposited between the dykes and the Robson-Broadwater Highway to levels not exceeding the highway grade.

The space between Spoil Areas 4 and 5 is currently used to some extent as an informal beach area. Disturbance of this area would be avoided.

SECTION 7.0 - POWERPLANT OPERATION

7.1 OPERATING REGIME

As a result of the addition of generating facilities at Keenleyside and the construction of the downstream Murphy Creek Project, the existing operating regime for the Arrow Lakes Reservoir and Keenleyside Dam would likely be changed. Although, as discussed in Section 4.0, the powerplant may operate initially under conditions close to Regime 1, it is expected that Regime 2 would be much more representative of long-term operation. Therefore, the effects on reservoir levels, discharges and tailwater levels as discussed in the following sections are based solely on Regime 2.

7.2 RESERVOIR LEVELS AND DISCHARGES

Compared to existing conditions with no generating facilities, the most significant changes in operation would be the reduced drawdown of the Arrow Lakes Reservoir, a more uniform discharge throughout the year and, most importantly, the diversion of much of the discharge from the sluiceway to the powerplant. Based on monthly computer simulations for the 35-year period from August 1940 to July 1975, the increase in mean spring time reservoir levels for the Arrow Lakes would be as follows:

Mean Monthly Arrow Lakes Reservoir El. (m)

Month	Existing Operation (Regime 1)	Powerplant Operation (Regime 2)	Increase (m)
Jan.	432.0	436.1	4.1
Feb.	424.3	433.0	8.7
Mar.	421.2	429.5	8.3
Apr.	421.5	427.9	6.4
May	424.4	429.9	5.5
June	431.3	435.1	3.8

The 35-year mean monthly discharges (total of all facilities) from Keenleyside during the reservoir drawdown and refilling period would be changed as follows:

Mean Monthly Discharge (m^3/s)

Month	Existing Operation	Powerplant Operation	Change (%)
Dec.	1311	1245	-5
Jan.	2399	1446	-40
Feb.	1971	1582	-20
Mar.	779	1369	+76
Apr.	816	806	-1
May	812	1029	+27
June	646	824	+28
July	920	1428	+55
Aug.	1463	1480	+1

Under existing conditions without the powerplant, most of the water at Keenleyside is discharged through the sluiceway and results in severe gas supersaturation downstream. With the powerplant installed and operated according to Regime 2, approximately 73 percent of the total releases would be made through the powerplant.

7.3 TAILWATER LEVELS

The most significant changes in tailwater levels downstream of Keenleyside would be due to the reservoir created by the Murphy Creek Project (Ref. 5) which, with a nominal reservoir level of El. 424, would raise the average natural tailwater level at Keenleyside by about 4 m. However, under some flow and system load conditions it would be desirable to match the system load by varying the output at any or all of the Murphy Creek, Brilliant or Keenleyside powerplants. At such times this could result in daily water level variations of up to 2 m near Keenleyside.

To maximize overall generation at Keenleyside, Brilliant and Murphy (424), it would be desirable, except as required for occasional load shaping, to regulate the Murphy reservoir to maintain the tailwater level at Keenleyside as near as possible to El. 424 from mid-May to early March of the following year. However, in the spring when the Arrow Lakes Reservoir is drawn down and the available gross head is near the minimum of 7.0 m assumed for turbine operation, it would be possible to reduce the Keenleyside powerplant downtime by drawing the Murphy Creek reservoir down to lower the tailwater level at Keenleyside and thus maintain sufficient head for generation. The benefit from additional energy generated at Keenleyside (some benefit also at Brilliant) would exceed the loss of generation at Murphy Creek by a considerable margin for tailwater drawdowns up to about 1 m. The Keenleyside turbine setting of El. 420.0 has been based, therefore, on a minimum tailwater level (for generation) of El. 423. This lower setting will also provide some flexibility in the operation of the Murphy Creek Reservoir which, at times, may be difficult to regulate within narrow limits because of variations in either the Columbia or Kootenay river discharges, unscheduled loss of generator load and the significant backwater effects between Murphy Creek and Keenleyside.

In years of extreme potential for flooding, when the Arrow Lakes will still have to be drawn down to levels close to El. 420, it would be necessary to lower the Murphy Creek Reservoir also to permit the necessary releases from Keenleyside. These lower Murphy reservoir levels (below El. 423) would be required only when the Arrow Lakes Reservoir is below El. 430.0, the minimum level for generation at Keenleyside, and, therefore, would not affect Keenleyside generation.

7.4 GENERATION

The head, discharge and monthly average power potential under Regime 2, are shown graphically on Fig. 7-1. Average annual generation with the 210 MW capacity and including allowances for reservoir surcharge in high runoff years would be approximately 880 GW.h (100 average MW).

REFERENCES

1. C.B.A. Engineering Ltd. September 1962. Report on Power Studies for Arrow Lakes Dam.

2. Hydroelectric Generation Projects Division, B.C. Hydro. March 1981. Murphy Creek Project, Feasibility Study. Report No. H 1335.

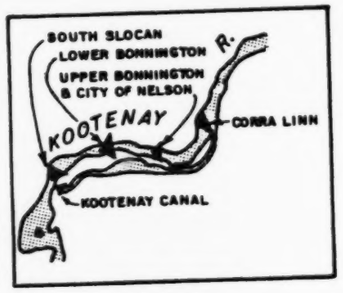
3. Hydroelectric Generation Projects Division, B.C. Hydro. July 1981. Hugh Keenleyside Powerplant, Prefeasibility Study. Report No. H 1374.

4. System Engineering Division, B.C. Hydro. July 1981. Economic Evaluation of Alternative Murphy Hydro Developments. Report No. SE 8113.

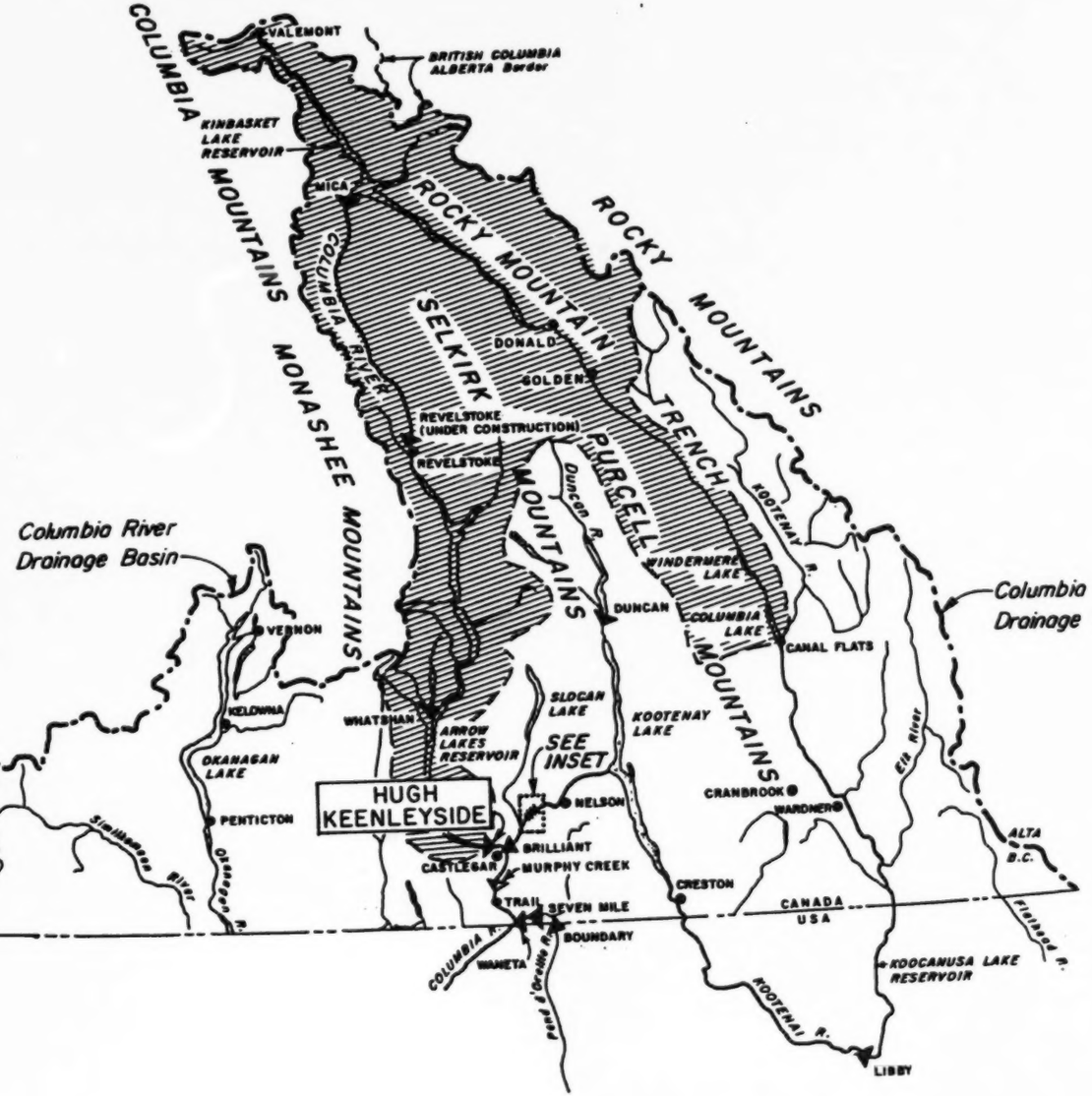
5. Hydroelectric Generation Projects Division, B.C. Hydro. November 1982. Murphy Creek Project, Engineering Description. Report No. H 1565.

6. System Engineering Division, B.C. Hydro. July 1982. Keenleyside Transmission Corridor Selection Studies. Report No. SE 8217.

7. Hydroelectric Generation Projects Division, B.C. Hydro. Hugh Keenleyside Powerplant, Preliminary Design Study, Review of Flood Criteria. Draft Report No. H 1497 dated June 1982.



INSET



SCALE IN KILOMETERS
20 0 20 40 60 80 100

KEY PLAN

LEGEND:

- City, town, or settlement
- Existing dam
- Potential dam
- Limit of drainage basin for Hugh Keenleyside Dam

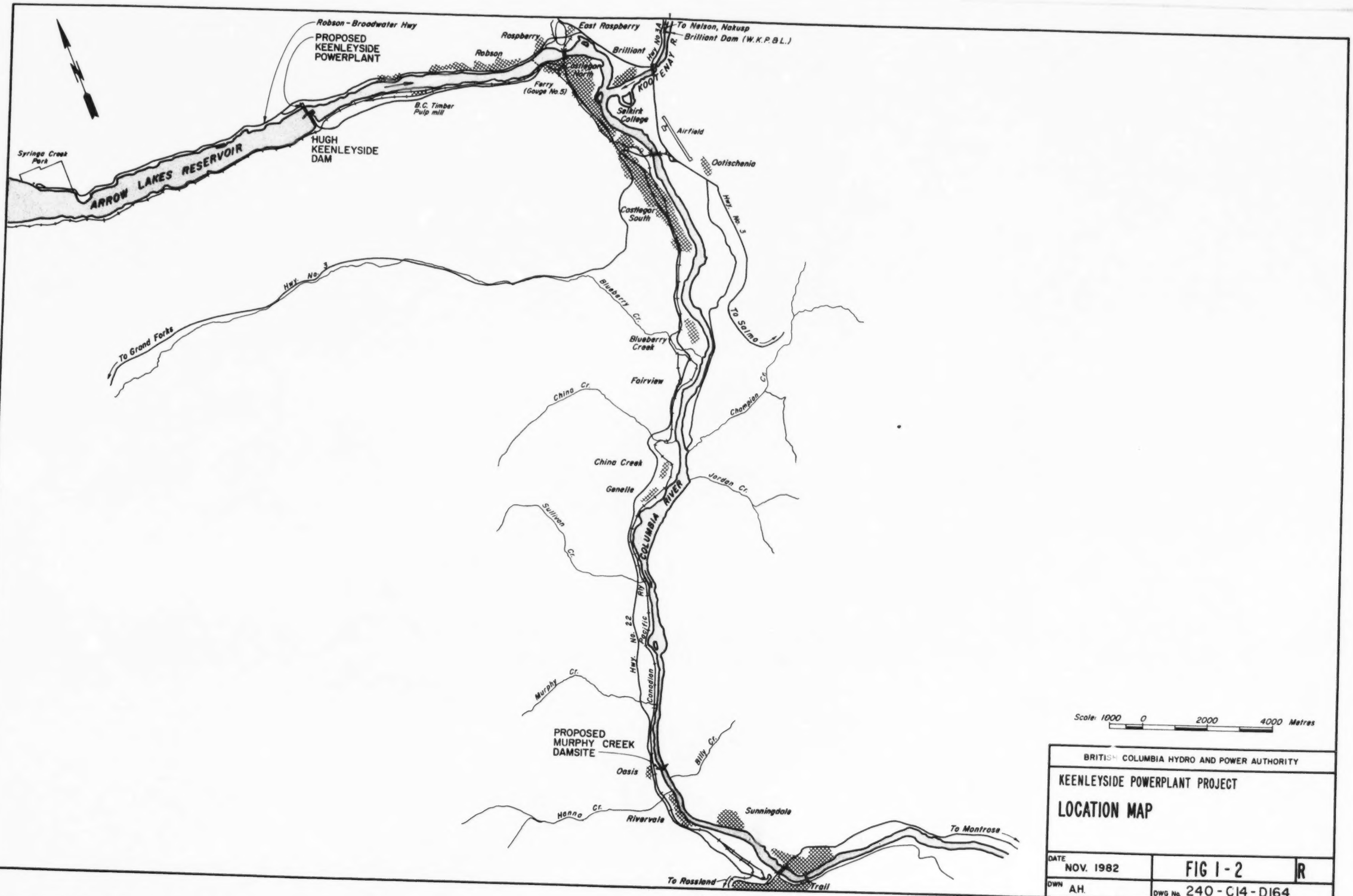
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

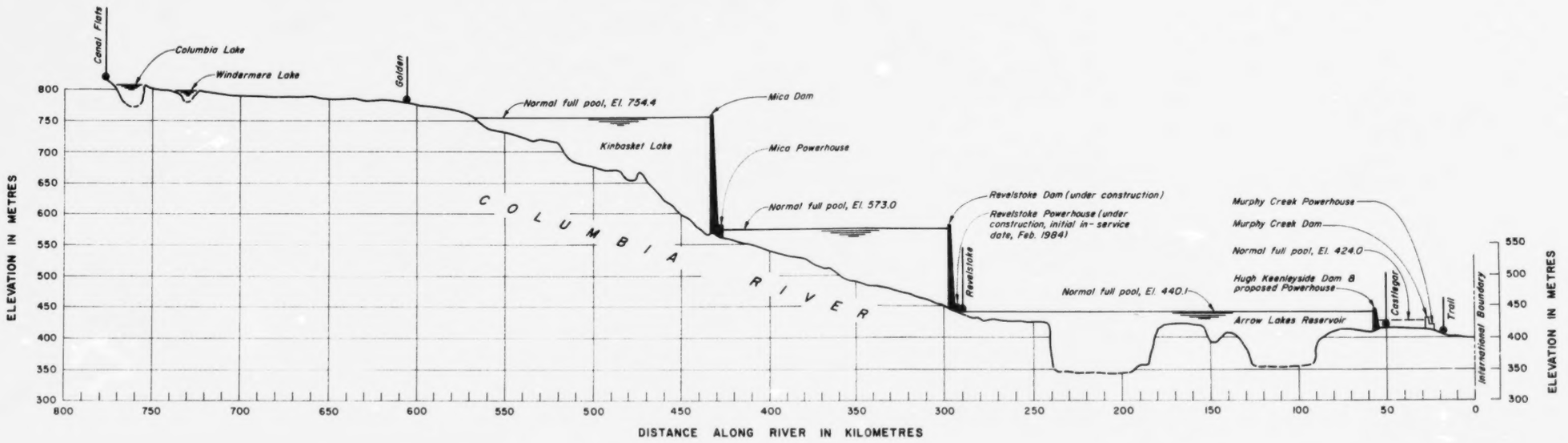
KEENLEYSIDE POWERPLANT PROJECT

KEY MAP

DATE NOV. 1982	FIG. 1-1
DWN N.O.	DWG. No 240-C14-B163

REPORT No. H1560


Robson - Broadwater Hwy
PROPOSED KEENLEYSIDE POWERPLANT
Raspberry
Robson
East Raspberry
Brilliant
Hwy. No. 3A
To Nelson, Nakusp
Brilliant Dam (W.K.P.&L.)
KOOTENAY R.
Castlegar North
Ferry (Gouge No. 5)
B.C. Timber Pulp mill
Selkirk College
Airfield
Ootischenia
Syringe Creek Park
ARROW LAKES RESERVOIR
HUGH KEENLEYSIDE DAM
Castlegar South
Hwy. No. 3
To Grand Forks
Blueberry Cr.
Blueberry Creek
To Salmo
Fairview
China Cr.
Champion Cr.
China Creek
Genelle
Jordan Cr.
Sullivan Cr.
COLUMBIA RIVER
Hwy. No. 22
Pacific
Canadian
Murphy Cr.
PROPOSED MURPHY CREEK DAMSITE
Oasis
Billy Cr.
Hanna Cr.
Rivervale
Sunningdale
To Montrose
To Rossland
Trail
Scale: 1000 0 2000 4000 Metres
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY
KEENLEYSIDE POWERPLANT PROJECT
LOCATION MAP
DATE NOV. 1982
FIG 1-2
R
DWN A.H.
DWG No. 240-C14-D164



RIVER PROFILE

LEGEND

- Existing
- Potential
- City or town

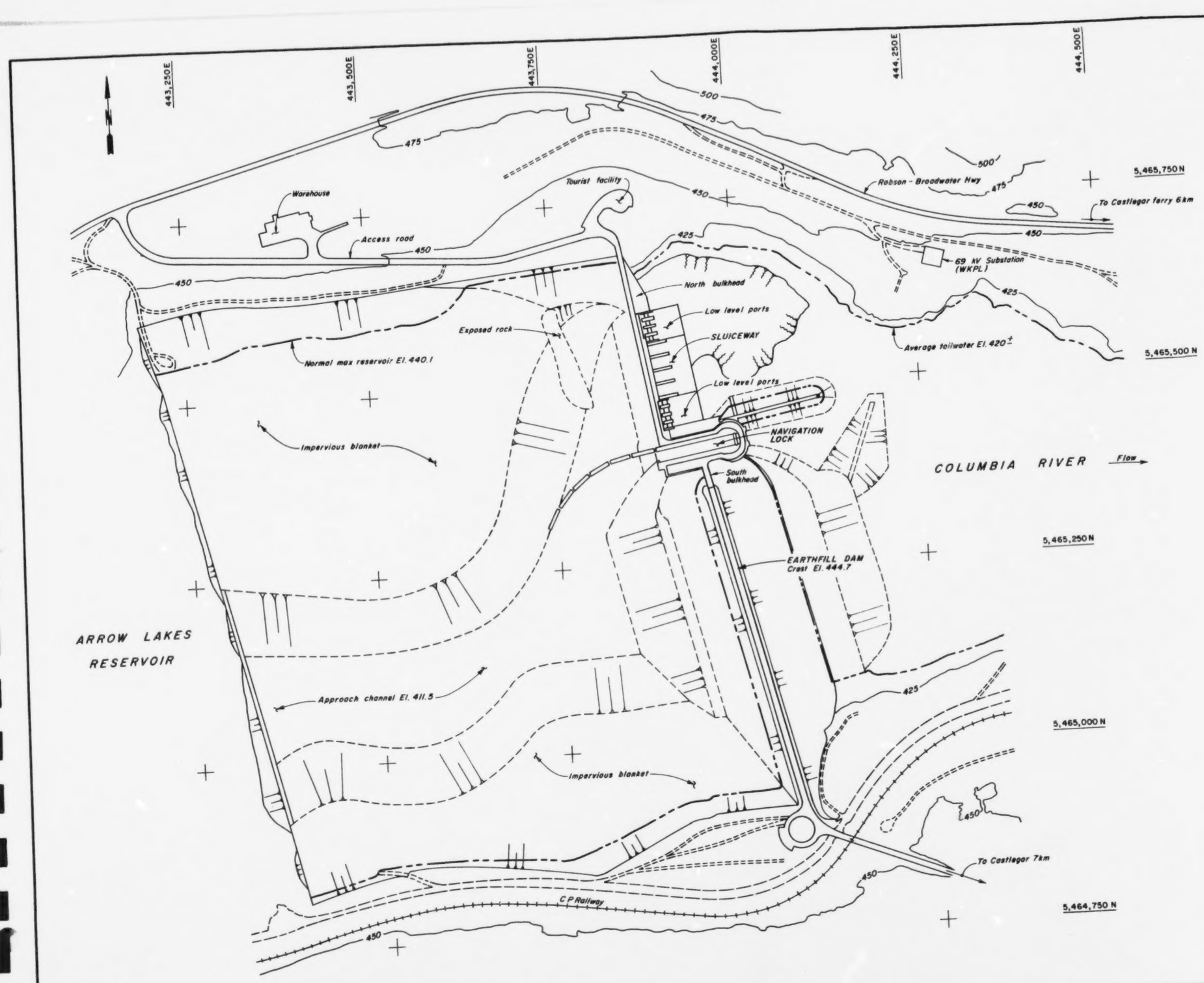
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

COLUMBIA RIVER PROFILE

DATE NOV 1982	FIG. 2-1	R
DWN SM	DWG No. 240-C14-D177	

REPORT No. H1560

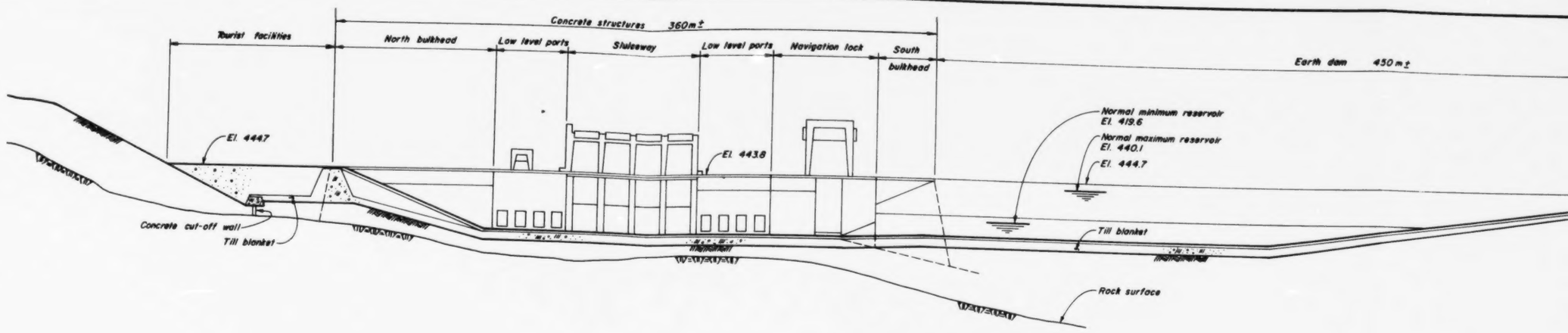


BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

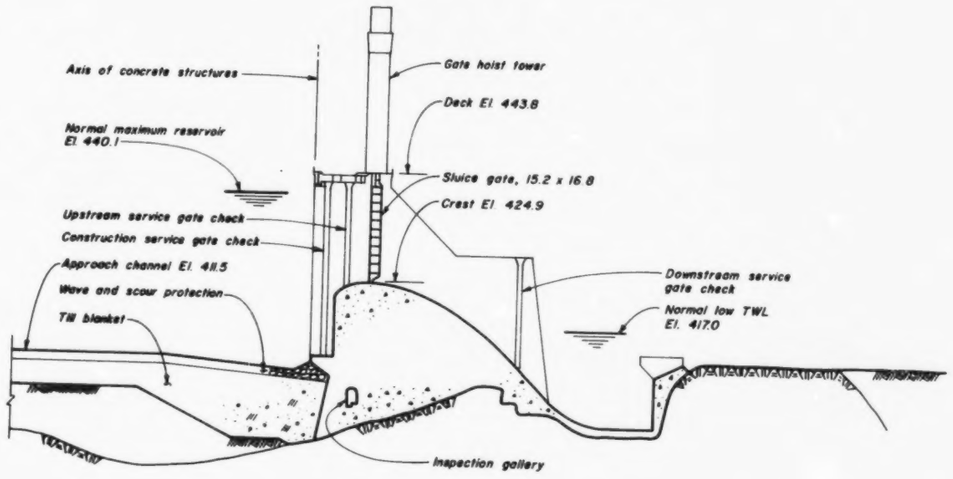
EXISTING DAM GENERAL ARRANGEMENT

DATE NOV. 1982	FIG 3-1	R
DWN DJ	DWG No. 240-C14-D165	

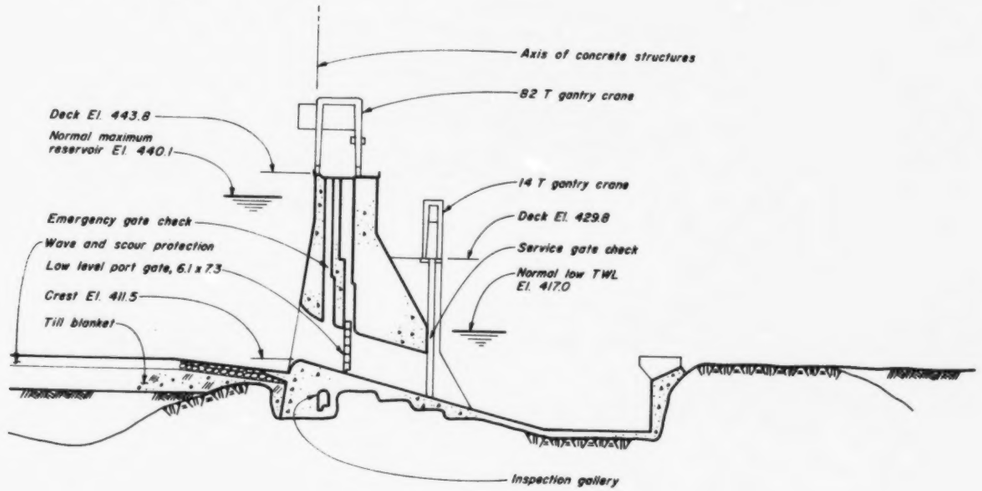


UPSTREAM ELEVATION

Scale A



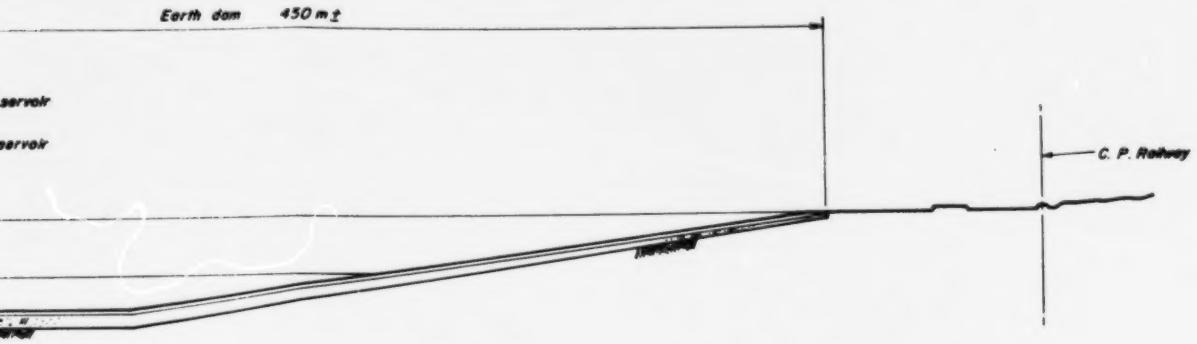
SLUICEWAY

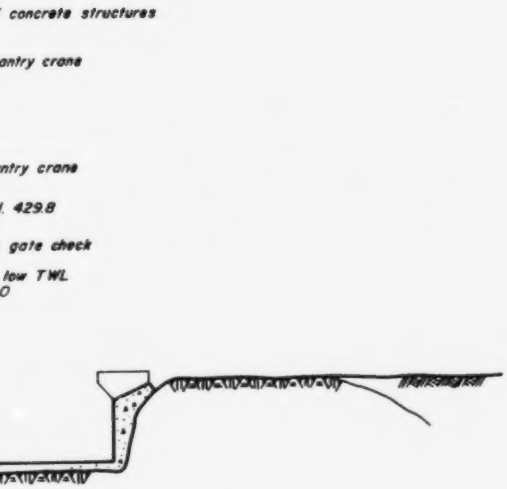


LOW LEVEL PORTS

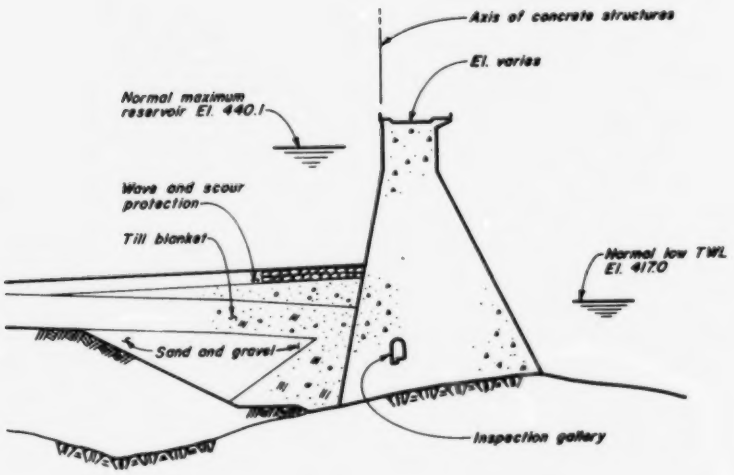
TYPICAL SECTIONS

Scale B





RTS



NORTH BULKHEAD

Scale: B 10 0 10 20 30 40 Metres

Scale: A 25 0 25 50 75 100 Metres

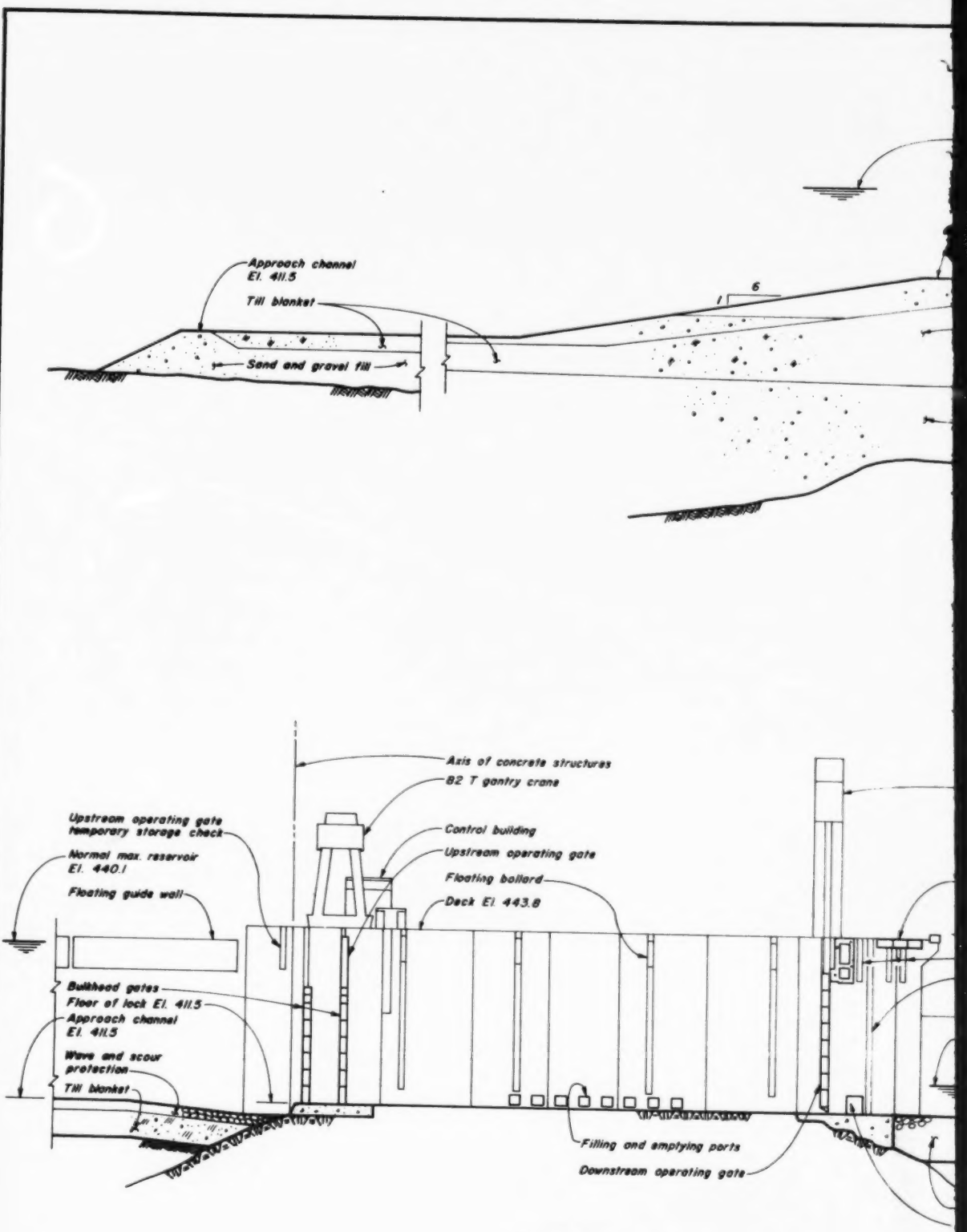
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

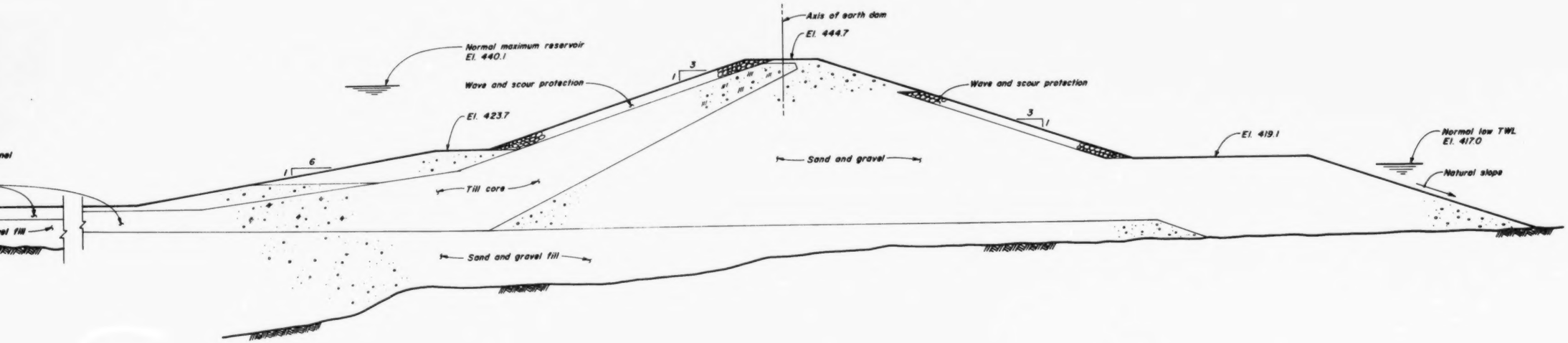
EXISTING DAM
ELEVATION & SECTIONS

DATE NOV. 1982	FIG. 3-2
DWN SM	DWG No. 240-C14-U166

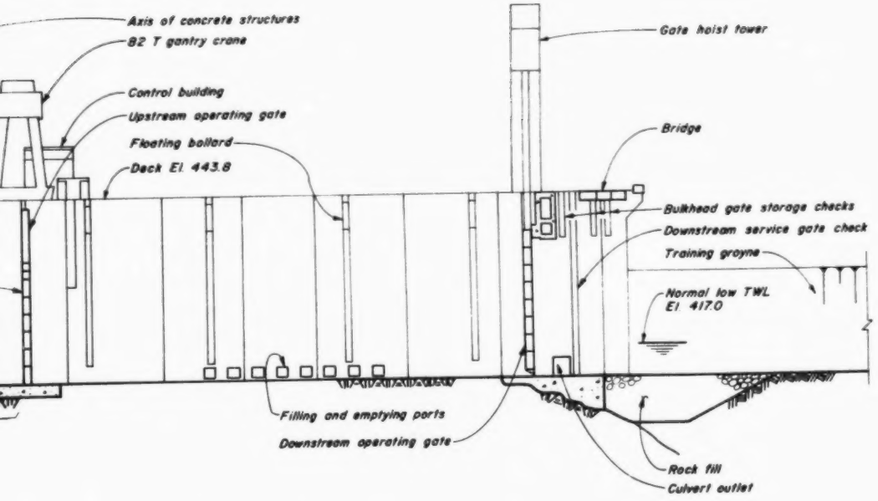
REPORT No. H1580



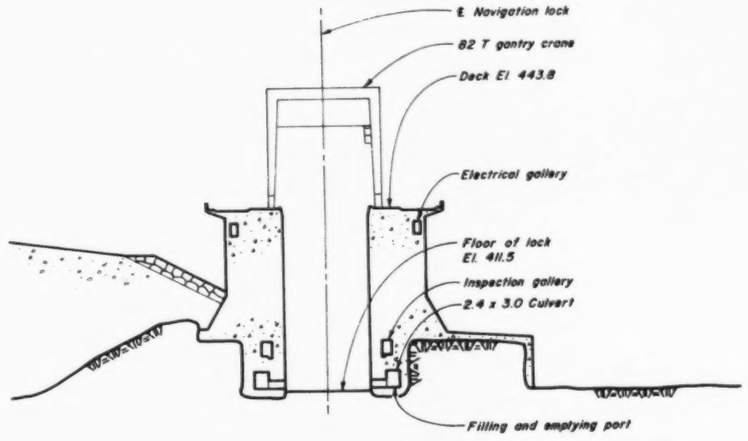
LONGITUDINAL SECTION
NAVIGATION LOCK



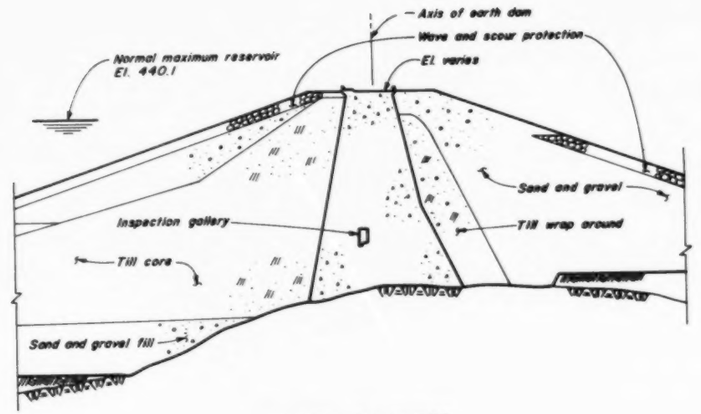
EARTH DAM



LONGITUDINAL SECTION
NAVIGATION LOCK



TRANSVERSE SECTION
NAVIGATION LOCK



SOUTH BULKHEAD

Scale: 10 0 10 20 30 40 Metres

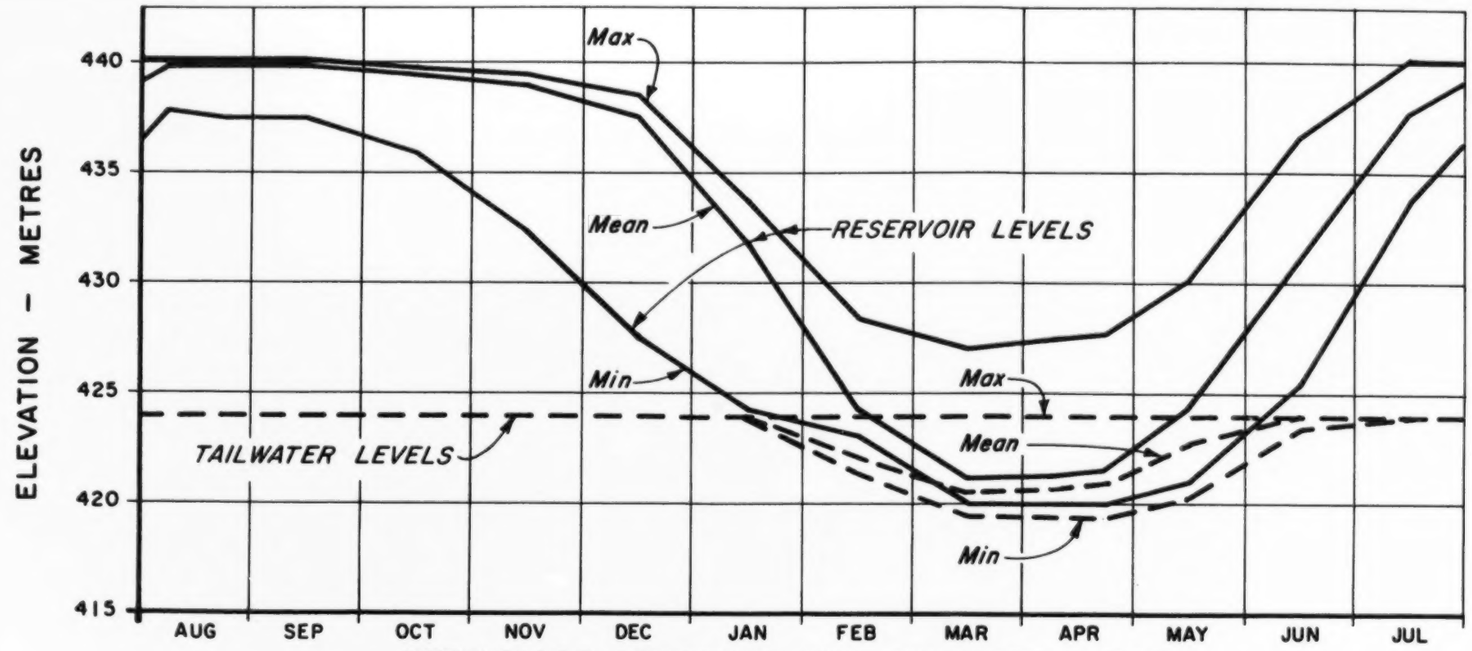
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

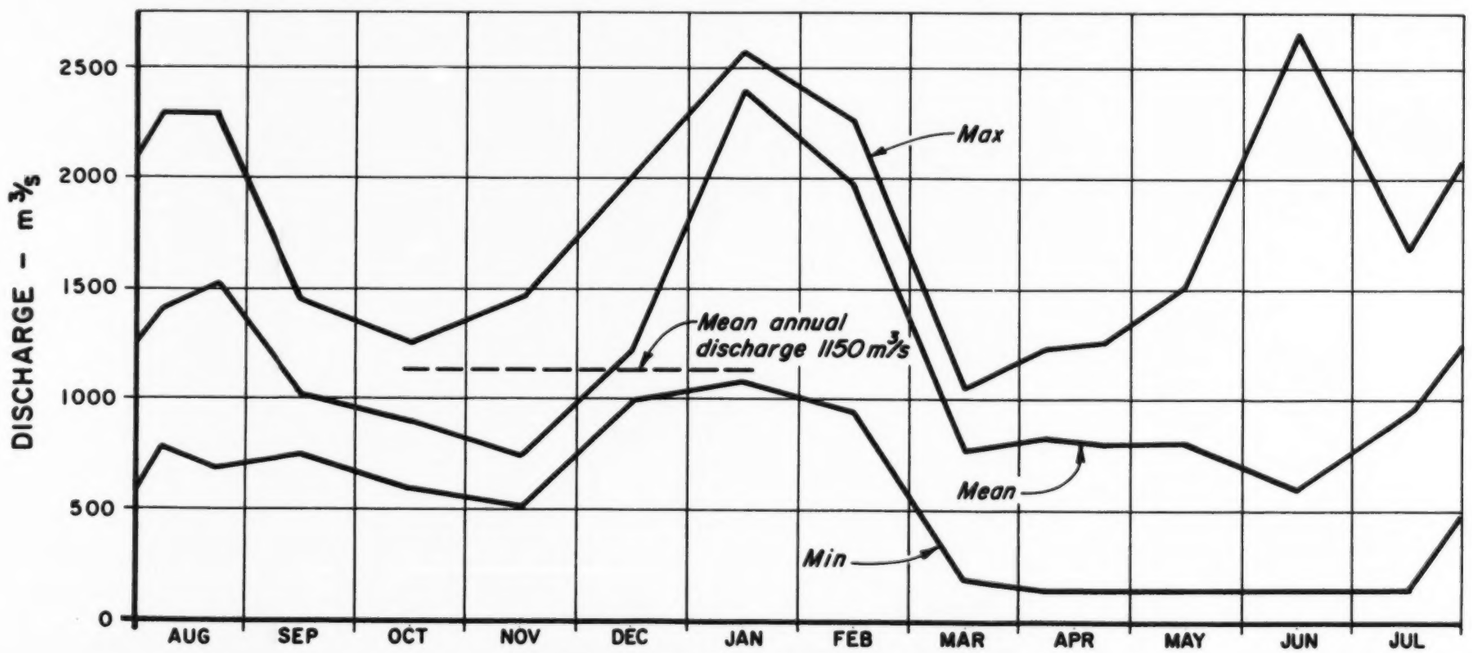
EXISTING DAM SECTIONS

DATE NOV. 1982	FIG. 3-3
DWN SM	DWG No 240-C14-U167

REPORT No. H1580



KEENLEYSIDE RESERVOIR AND TAILWATER LEVELS



KEENLEYSIDE TOTAL DISCHARGE

NOTE:

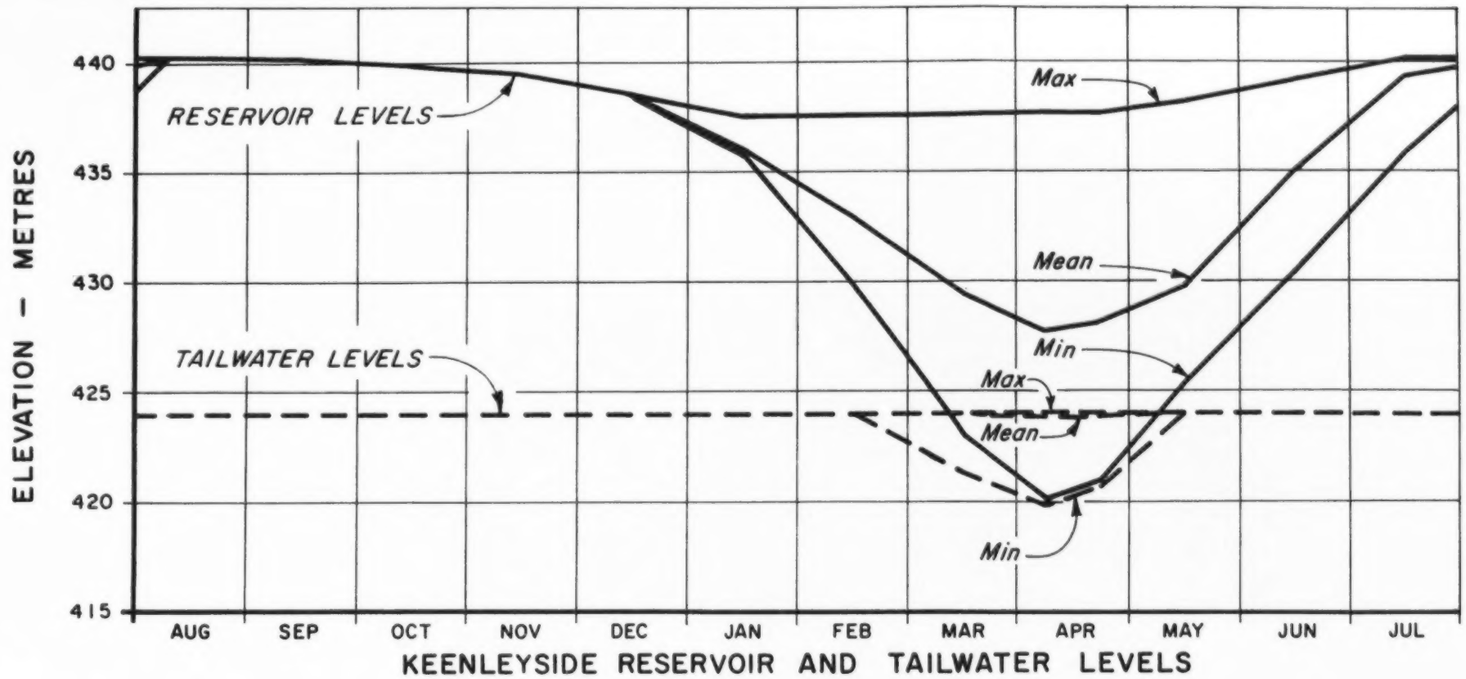
KEENLEYSIDE TAILWATER LEVELS ARE BASED ON A MURPHY CREEK PROJECT RESERVOIR ELEVATION LIMIT OF 424.0 m AT CASTLEGAR.

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

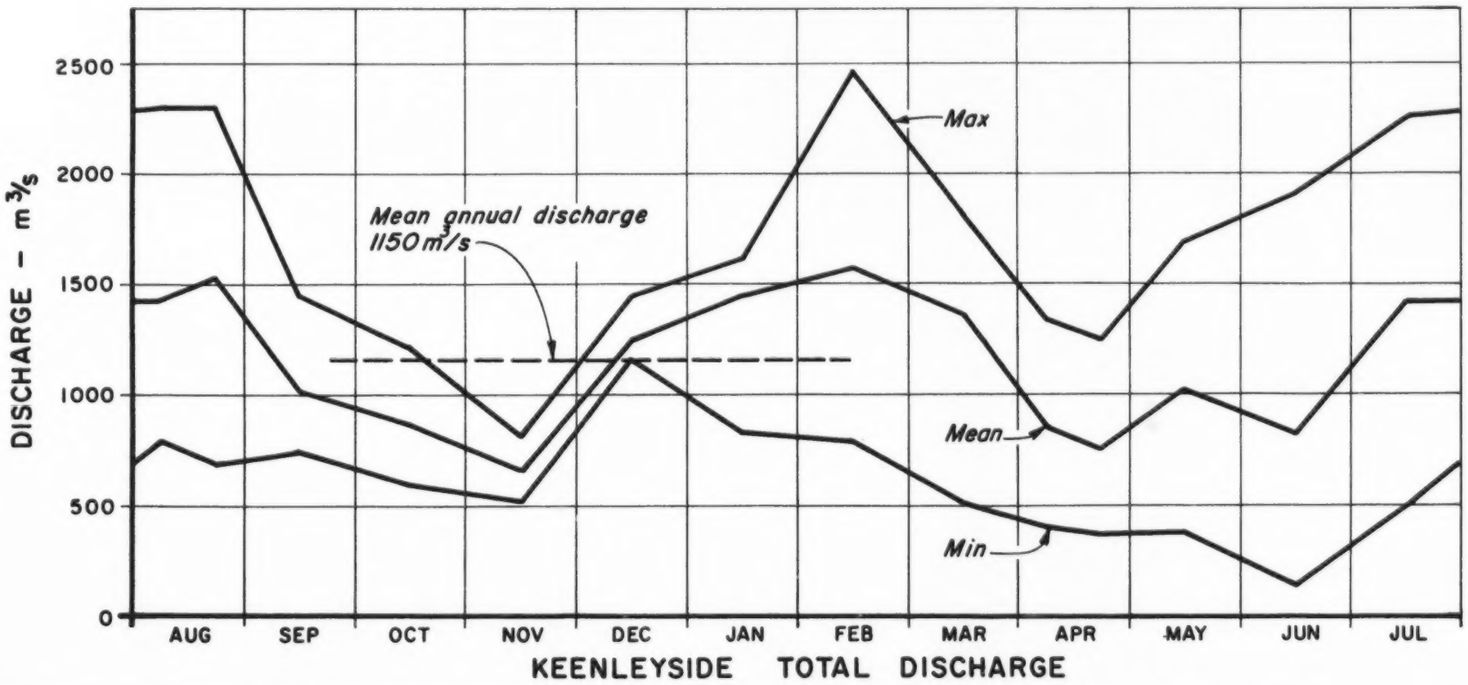
KEENLEYSIDE POWERPLANT PROJECT

TYPICAL RESERVOIR LEVELS & DISCHARGE HYDROGRAPHS - EXISTING OPERATION (REGIME 1)

DATE NOV. 1982	FIG 4 - 1
DWN KL	DWG. No. 240 - C14 - B168



KEENLEYSIDE RESERVOIR AND TAILWATER LEVELS



KEENLEYSIDE TOTAL DISCHARGE

NOTE:

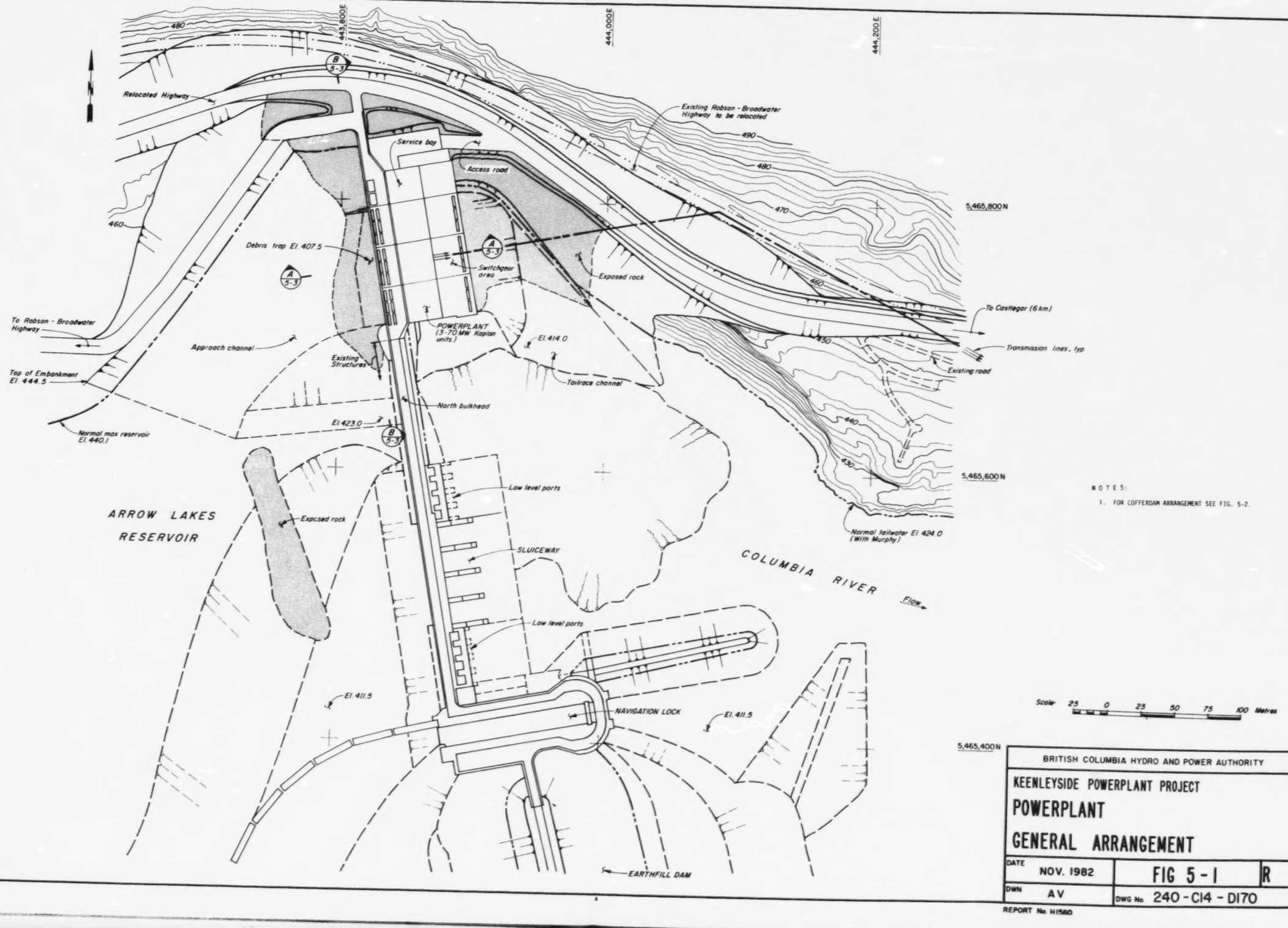
KEENLEYSIDE TAILWATER LEVELS ARE BASED ON A MURPHY CREEK PROJECT RESERVOIR ELEVATION LIMIT OF 424.0 m AT CASTLEGAR.

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

TYPICAL RESERVOIR LEVELS & DISCHARGE HYDROGRAPHS - FUTURE OPERATION (REGIME 2)

DATE NOV. 1982	FIG 4 - 2
DWN KL	DWG. No 240 - C14 - B169



NOTES:

1. FOR COFFERDAM ARRANGEMENT SEE FIG. 5-2.

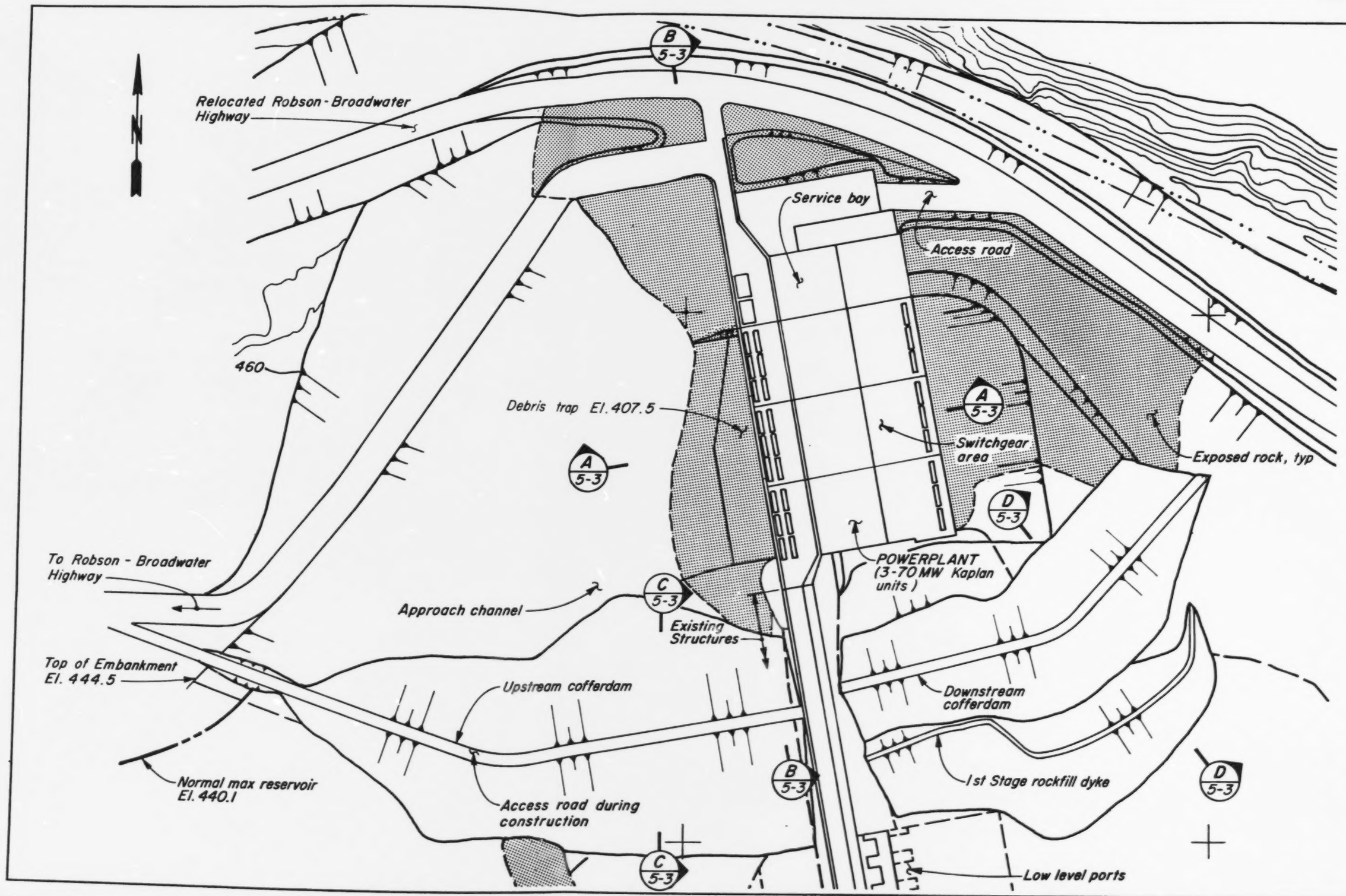
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

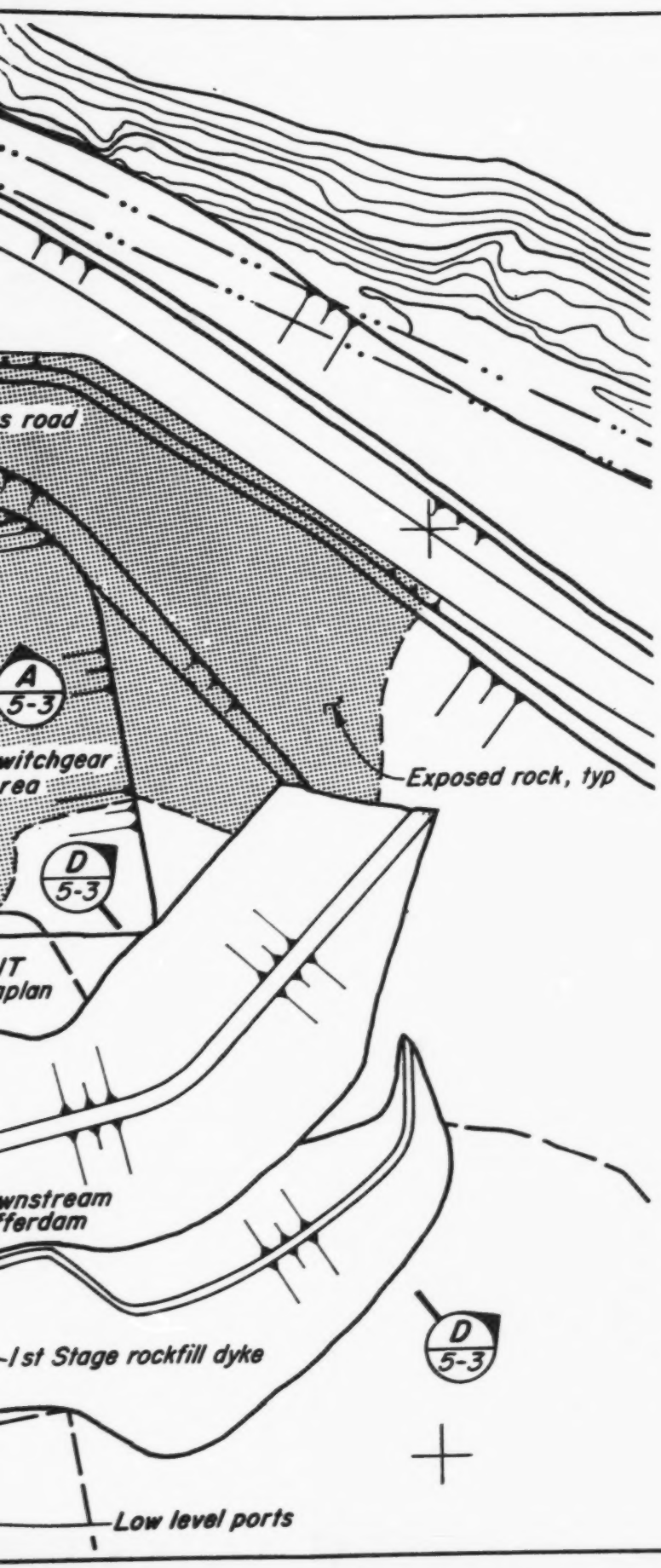
KEENLEYSIDE POWERPLANT PROJECT

POWERPLANT GENERAL ARRANGEMENT

DATE NOV. 1982	FIG 5 - 1	R
DWN AV	DWG No. 240 - C14 - D170	

REPORT No. H1580


N
B
5-3
Relocated Robson - Broadwater Highway
460
Debris trap El. 407.5
A
5-3
Service bay
Access road
A
5-3
Switchgear area
Exposed rock, typ
D
5-3
POWERPLANT (3-70 MW Kaplan units)
To Robson - Broadwater Highway
Approach channel
C
5-3
Existing Structures
Top of Embankment El. 444.5
Upstream cofferdam
Downstream cofferdam
B
5-3
1st Stage rockfill dyke
D
5-3
Normal max reservoir El. 440.1
Access road during construction
C
5-3
Low level ports



Scale: 0 25 50 Metres

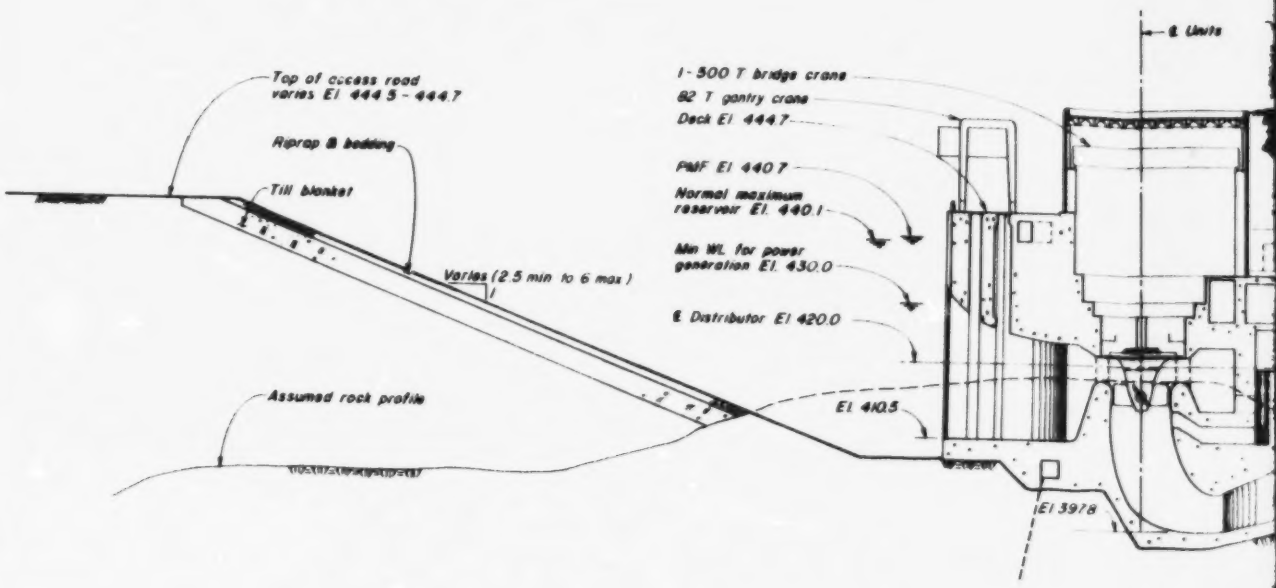
BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

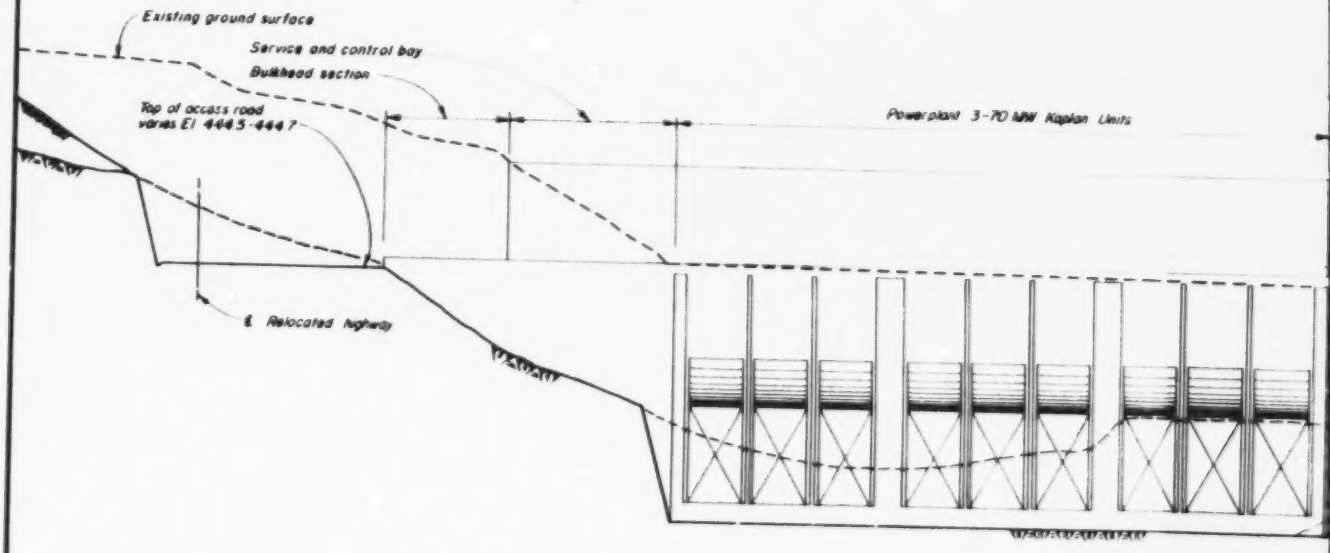
COFFERDAM ARRANGEMENT

DATE NOV. 1982	FIG 5-2
DWN A.V.	DWG No 240-C14-C176

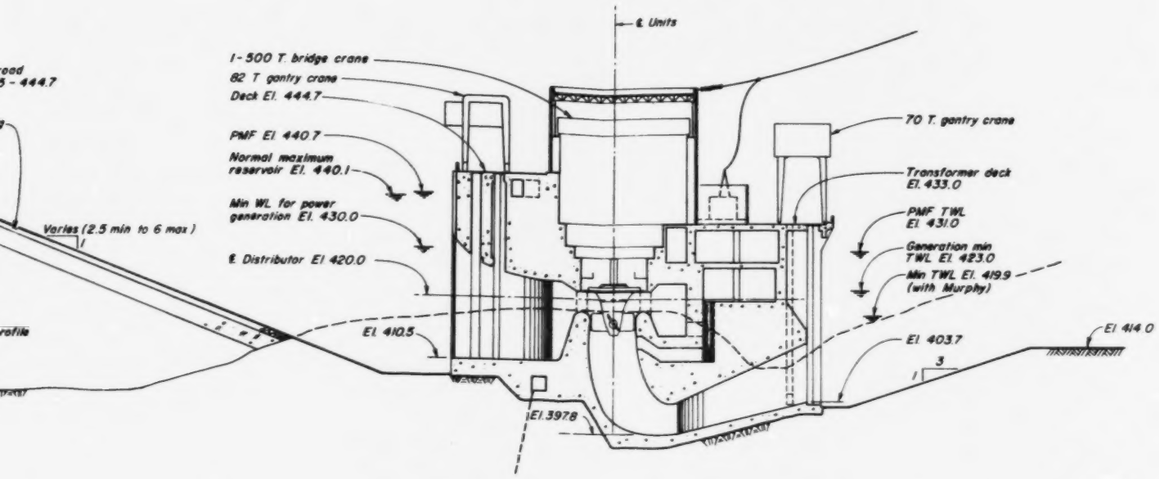
REPORT No. H1560



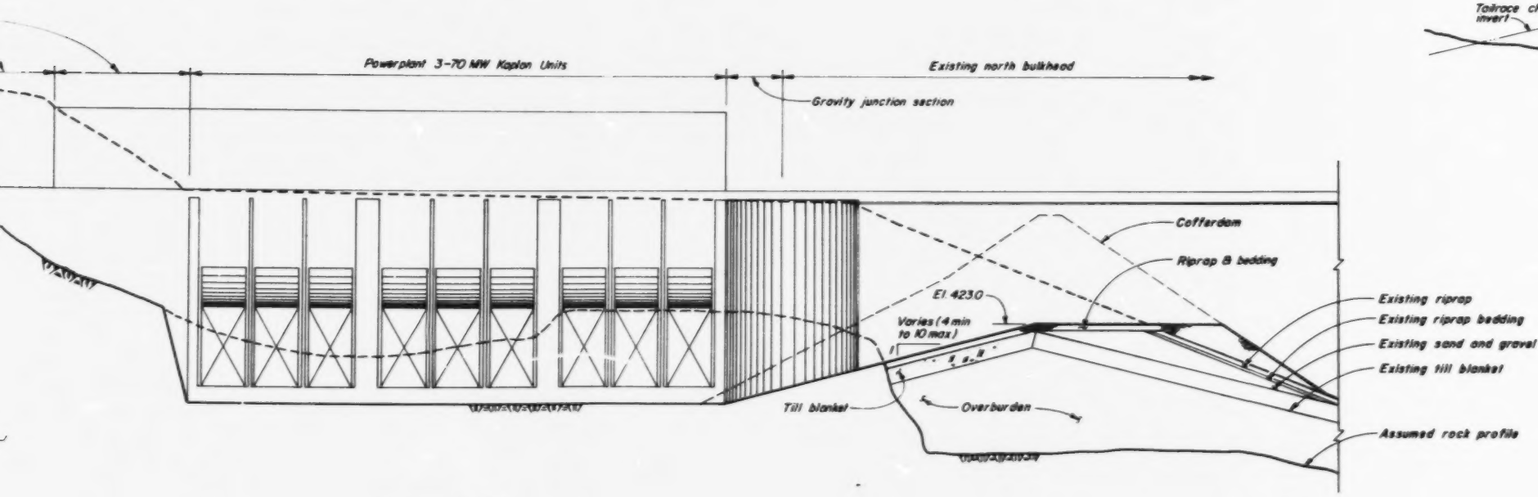
SECTION (A / 5-1)



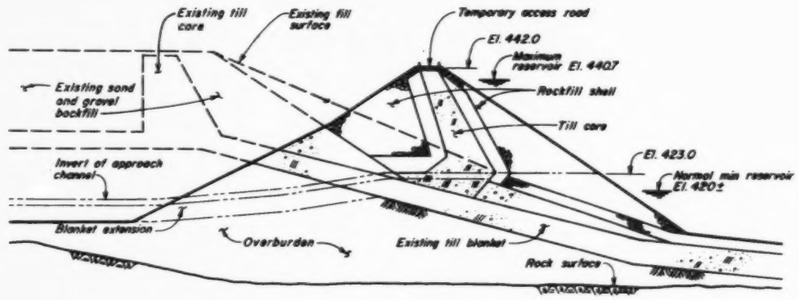
SECTION (B / 5-1)



SECTION (A 5-1)

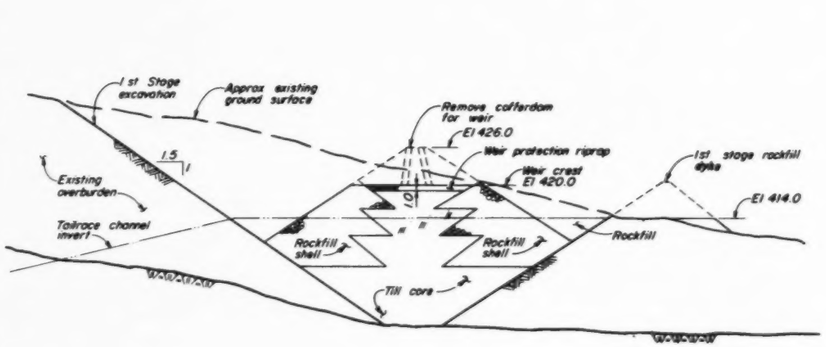


SECTION (B 5-1)



SECTION (C 5-2)

UPSTREAM COFFERDAM



SECTION (D 5-2)

DOWNSTREAM COFFERDAM

Scale: 10 0 10 20 30 40 Metres

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

POWERPLANT & COFFERDAMS SECTIONS

DATE NOV. 1982	FIG. 5-3	R
DWN FL/SM	DWG No. 240-C14-U171	

REPORT No. H1580

1984 | 1985 | 1986 | 1987 | 1988 | 1989 | 1990

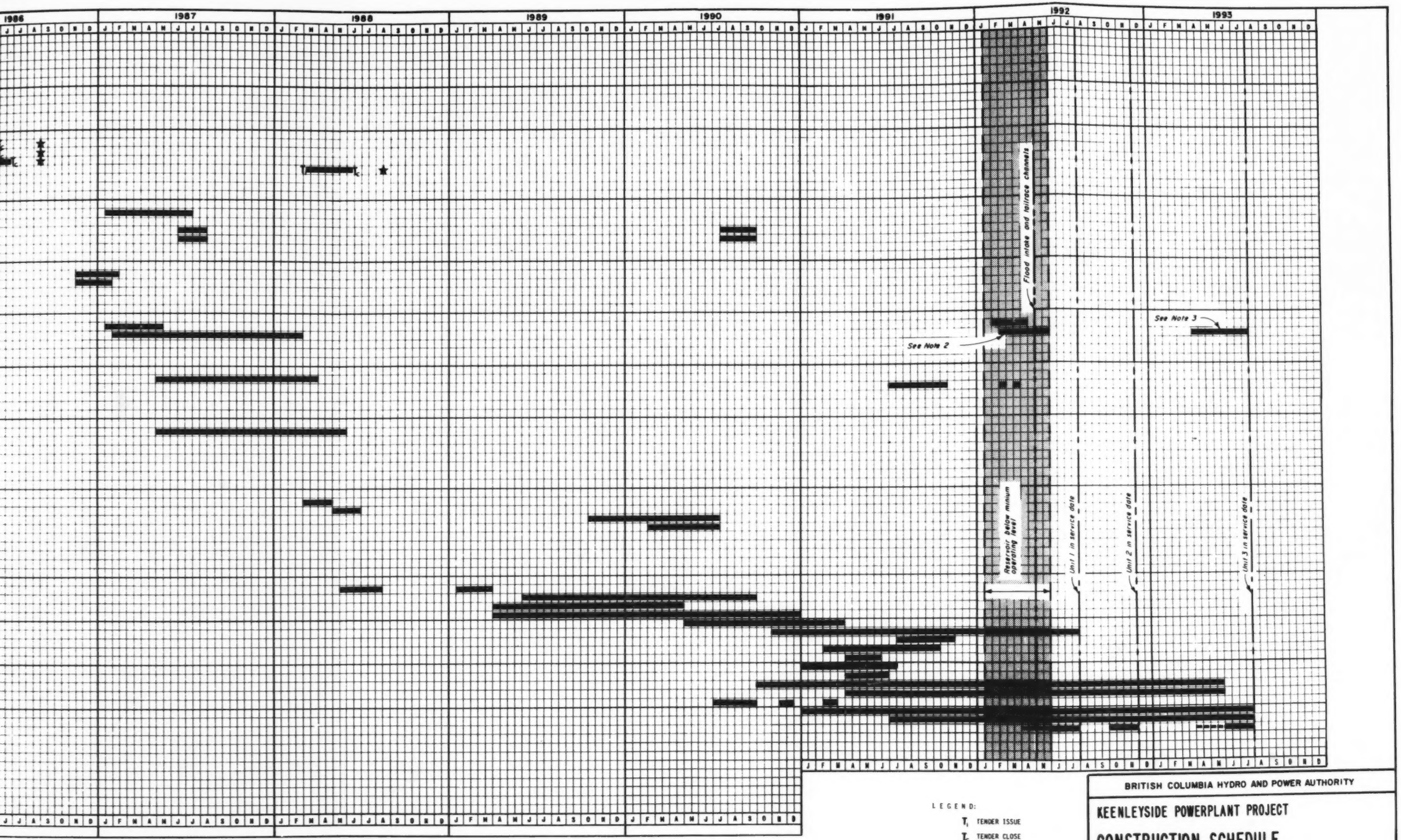
J F M A M J J A S O N D

- LICENCING
- TENDERING AND CONTRACT AWARDS
  - TURBINES AND GOVERNORS
  - GENERATORS
  - EXCAVATION AND COFFERDAMS
  - POWERPLANT STRUCTURAL AND COMPLETION
- ACCESS AND RELOCATIONS
  - HIGHWAY RELOCATION
  - POWERHOUSE ACCESS ROAD AND YARD
  - DAM CREST ACCESS ROAD
- BC HYDRO CONSTRUCTION FACILITIES
  - SINGLE LABOUR CAMP
  - OFFICES AND BUILDINGS
- COFFERDAMS
  - UPSTREAM COFFERDAM
  - DOWNSTREAM COFFERDAM
- INTAKE CHANNEL
  - EXCAVATION
  - BLANKET
- TAILRACE CHANNEL
  - EXCAVATION
- CONCRETE GRAVITY DAM
  - REMOVE EXISTING ABUTMENT SECTION
  - EXCAVATION
  - CONCRETE JUNCTION SECTION
  - CONCRETE LEFT BANK SECTION
- INTAKE AND POWERHOUSE
  - EXCAVATION
  - CONCRETE - POWER INTAKES
  - - FIRST STAGE - SERVICE BAY
  - - UNIT BAY
  - STEEL SUPERSTUCTURE AND ROOF
  - ARCHITECTURAL
  - TRASH RACKS
  - INTAKE GATES
  - INTAKE GANTRY CRANE
  - DRAFT TUBE GATES
  - TAILRACE GANTRY CRANE
  - TURBINES AND GOVERNORS
  - GENERATORS
  - BRIDGE CRANE
  - AUXILIARY MECHANICAL AND ELECTRICAL EQUIPMENT
  - TRANSFORMERS AND SWITCHGEAR
  - TEST & COMMISSION

Project approval

NOTES:

1. PROJECT APPROVAL IS REQUIR
2. A WEIR, EXCAVATED IN THE D TO MAINTAIN TAILWATER LEVE
3. AFTER IMPOUNDING OF RUNOFF REMOVAL OF THE DOWNSTREAM TAILRACE TO FULL DEPTH.



NOTES:

1. PROJECT APPROVAL IS REQUIRED BY 1 JAN 1985.
2. A WEIR, EXCAVATED IN THE DOWNSTREAM COFFERDAM, WILL BE REQUIRED TO MAINTAIN TAILWATER LEVELS UNTIL MURPHY CREEK RESERVOIR IS IMPOUNDED.
3. AFTER IMPOUNDING OF MURPHY CREEK RESERVOIR, FURTHER EXCAVATION AND REMOVAL OF THE DOWNSTREAM COFFERDAM WILL BE REQUIRED TO INCREASE TAILRACE TO FULL DEPTH.

LEGEND:

- T_i TENDER ISSUE
- T_c TENDER CLOSE
- ★ CONTRACT AWARD
- WET TESTING DEFERRED - (LOW RESERVOIR LEVELS)

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

CONSTRUCTION SCHEDULE

DATE NOV. 1982	FIG. 6-1	R
DWN R.K.W	DWG No. 240-C14-X172	

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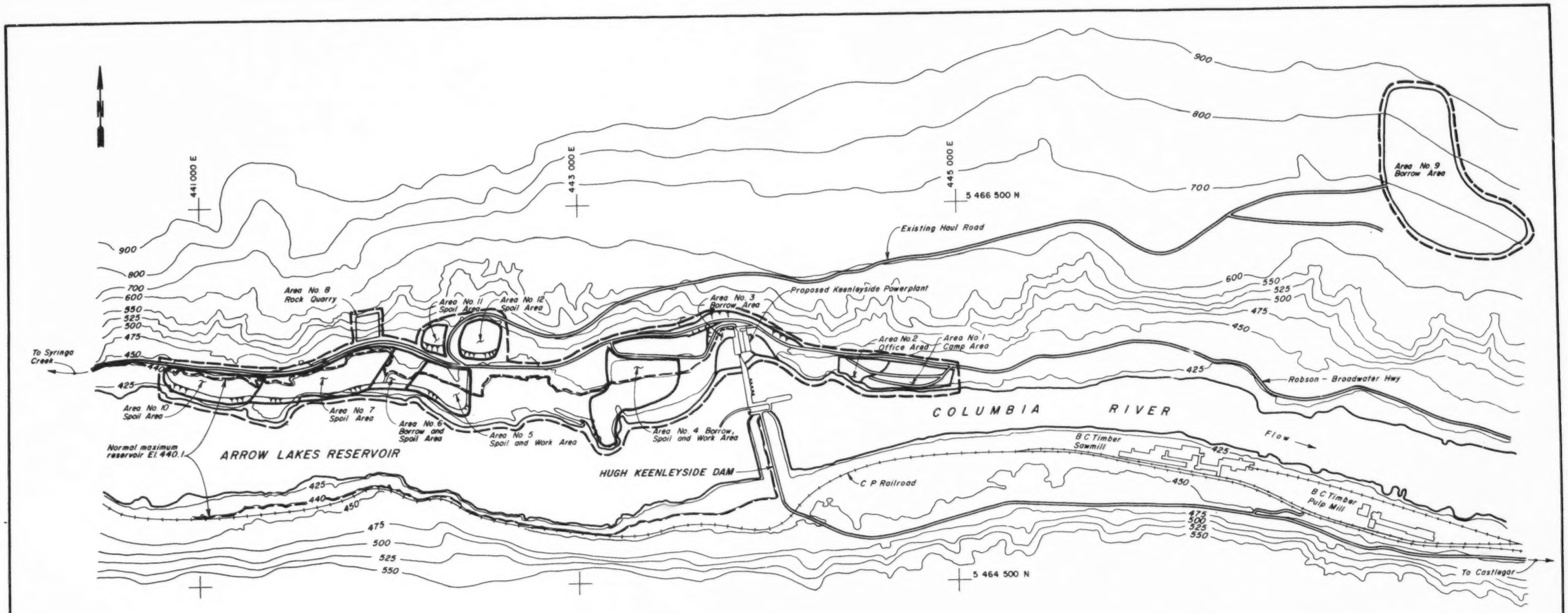


LIMIT OF CONSTRUCTION AREAS

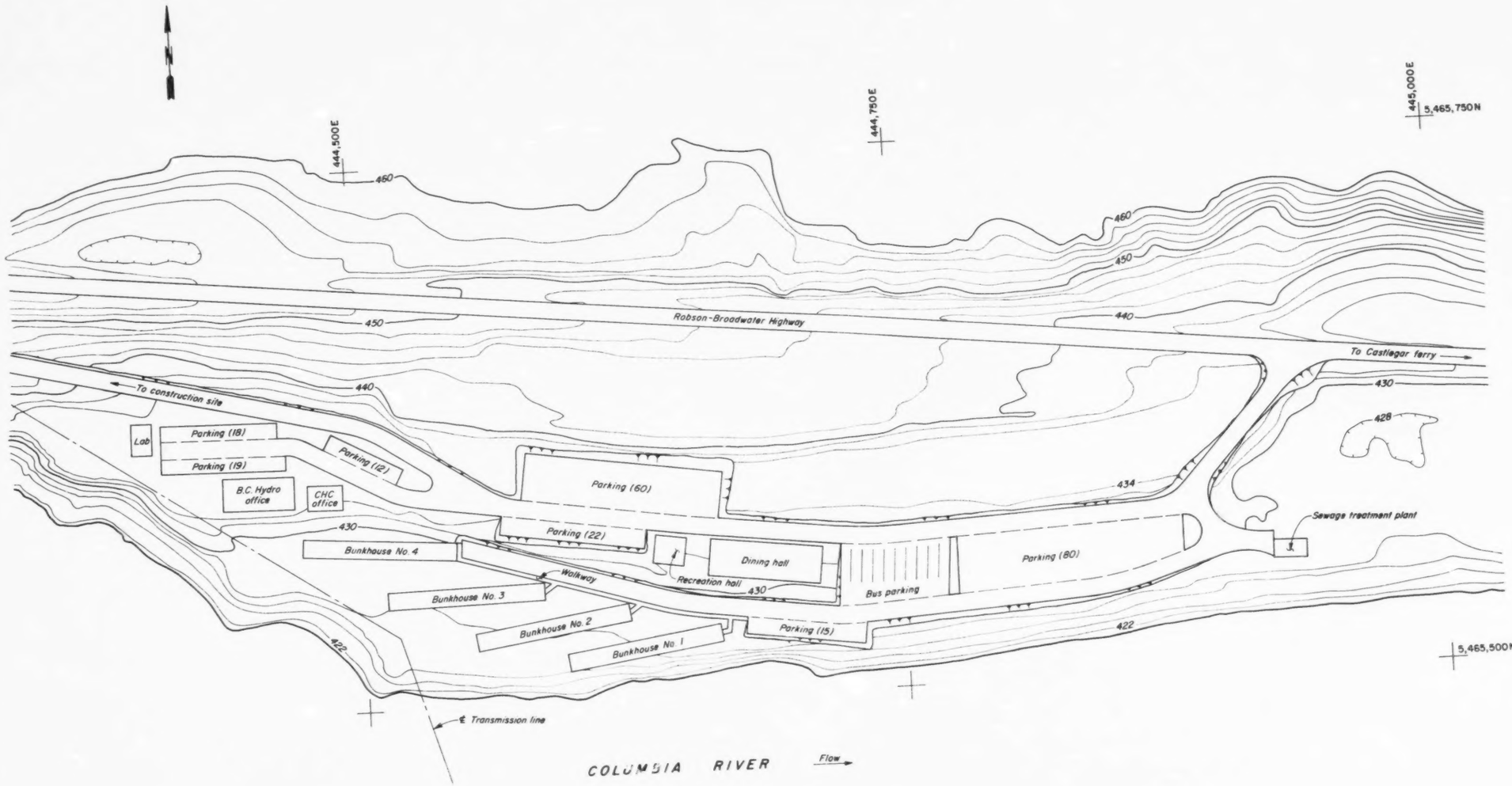
Scale: 200 0 200 400 600 800 Metres

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

POTENTIAL AREAS FOR CONSTRUCTION FACILITIES

DATE NOV. 1982	FIG 6-2	R
DWN SM	DWG No. 240-C14-D173	



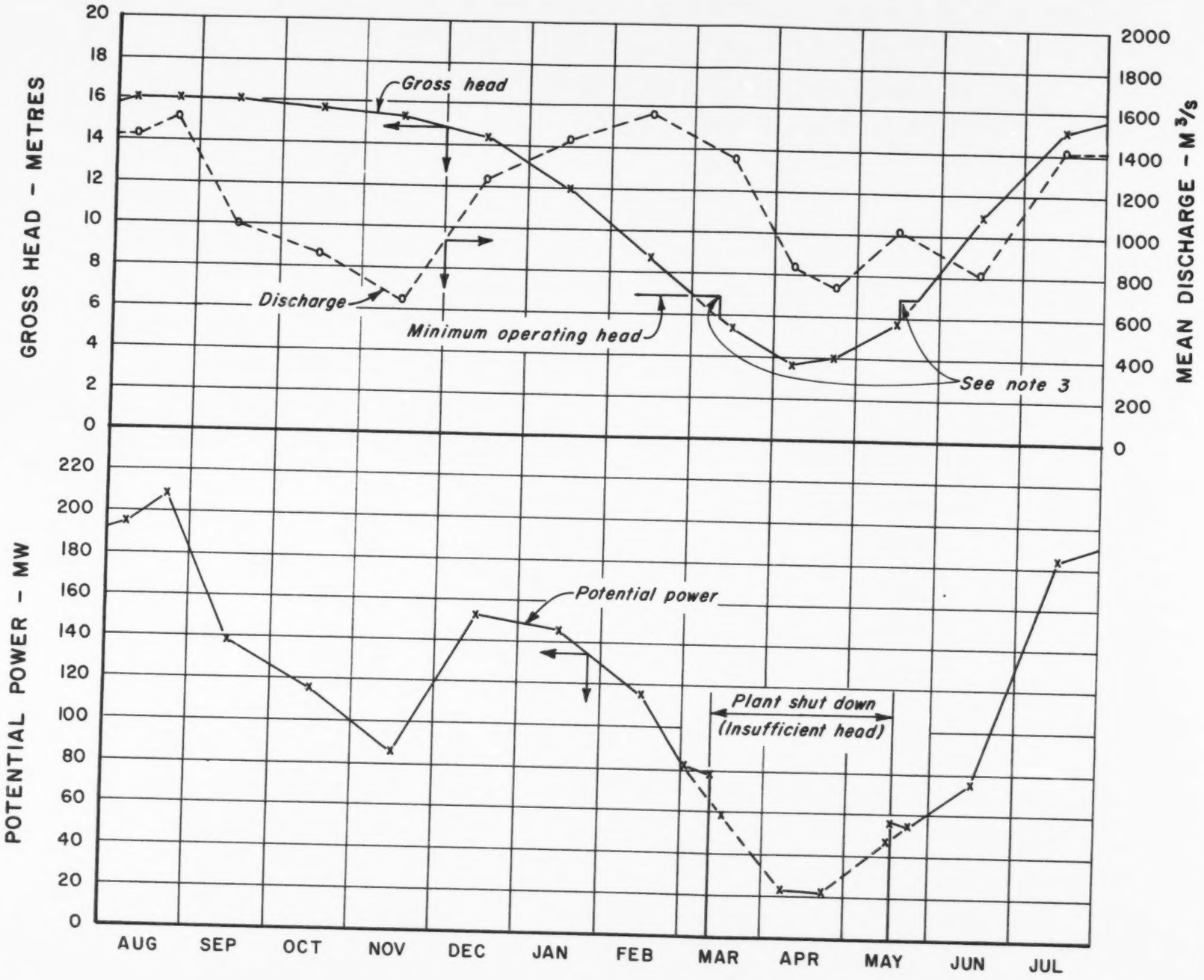
Scale: 20 0 20 40 60 80 Metres

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

CONSTRUCTION CAMP & OFFICES GENERAL ARRANGEMENT

DATE NOV. 1982	FIG 6-3	R
DWN A.V.	DWG No. 240-C14-D174	



NOTES:

1. POTENTIAL POWER IS BASED ON 35 YEAR MEAN MONTHLY VALUES OF GROSS HEAD AND TOTAL DISCHARGE. AN AVERAGE HEAD LOSS OF 0.6 m AND AND OVERALL PLANT EFFICIENCY OF 0.90 HAVE BEEN ASSUMED.
2. THE EFFECTS OF RESERVOIR SURCHARGE IN HIGH RUNOFF YEARS ARE NOT INCLUDED.
3. TAILWATER (MURPHY RES.) LOWERED TO MAINTAIN SUFFICIENT HEAD FOR GENERATION AT KEENLEYSIDE.

BRITISH COLUMBIA HYDRO AND POWER AUTHORITY

KEENLEYSIDE POWERPLANT PROJECT

MEAN MONTHLY DISCHARGE, HEAD AND POWER FUTURE OPERATION (REGIME 2)

DATE	FIG 7-1
NOV. 1982	
DWN DJ	Dwg. No 240-C14-B175

REPORT No H1560

POOR

QUALITY

ORIGINAL